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SIMULANT REACTION TEMPERATURE MEASUREMENT VIA TELEMETRY FOR THE XM736 AT CHARGE 9

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May 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Six XM736 projectiles were fitted with a payload temperature measurement/telemetry system and fired at Charge 9 with flight times of approximately 100 seconds. Temperatures of the reaction produced by the liquid simulants were as high as 350°C during the terminal portions of the trajectory. These high temperatures may be related to recent base failures that occurred during safety tests.

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I. INTRODUCTION

Six XM736 projectiles were flight tested at Dugway Proving Ground, (DPG), Utah, on 16 November 1978. These projectiles were instrumented with a payload temperature measurement system and a telemetry link. The projectiles were conditioned to 62°C and fired at Charge 9 (powder conditioned to either 21° or 62°C) with a quadrant elevation of approximately 60 degrees. These launch conditions would produce flight times of at least 100 seconds. These launch conditions were tested since premature expulsion of the binary canisters and simulants had occurred in the 75-100 second time frame during safety assurance tests. Data were received from four of the six projectiles and indicated payload temperatures as high as 350°C. The causes of these high temperatures and possible base failure modes will not be addressed within this report. Discussions of the accuracy and reliability of the measurements are made.

II. BACKGROUND

During the XM736 DT II safety tests, premature releases of the payload were experienced at Charge 9 when the projectile and the propellant were conditioned at 62°C. A Red Team was established by the Commander/Director of the Chemical Systems Laboratory to investigate this failure. Since premature payload ejection was only experienced with reactive simulants (as opposed to non-reactive simulants) and occurred most frequently when the projectile and the powder were conditioned to 62°C, it was concluded the exothermic reaction of the simulants and the launch conditions were intimately involved with the mode of failure. Earlier in the development cycle of the XM736, in-flight measurements of simulant payload temperature were made to address the mixing of the simulants[1]. However, most of that data were not applicable to the failure observed during the safety tests. Prior to the failures that occurred within the safety test, a group of six projectiles had been fabricated using the concepts within Reference 1. Although these projectiles and the measurement systems had not been specifically designed for conditioning to 62°C or high zone launch, they were employed in an attempt to gather data at the critical conditions. Several problems did occur with the measurement systems, but a reasonable amount of data was obtained.

III. INSTRUMENTATION

A. Projectile Measurement System

The temperature measurement system and the telemetry link for the projectiles were the same as those reported in Reference 1. A brief summary will be presented here. Figure 1 shows a cut-away view of the XM736 hardware used during DT II. The projectile hardware used in

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1. *W.P. D'Amico, W.H. Clay, A. Mark, and W.H. Mermagen, "In-Flight Payload Temperature Measurements for the XM736 Binary Projectile", BRL MR 2560, November 1975, AD B008702L.*

the temperature measurement program was essentially as shown in Figure 1 except the two canisters were welded together to produce an integral payload container, the base torque pin was eliminated in favor of two keys located along the outer wall of the canister, and circular shims eliminated gross longitudinal motion. These modifications were required to assure electrical continuity of the sensor leads. Telemetry was mounted in the ogive.

Temperature measurement was provided by 10 mil glass thermistor beads mounted in epoxy on the tip of a brass shank (see Figure 2). The location of the thermistors within the payload canister and the depths of protrusion (labeled A on Figure 2) are shown in Figure 3. Measurement positions T2, T4, T6, and T8 were located on one side of the canister while positions T3, T5, T7, and T9 were located 180 degrees on the other side of the canister. Position T10 was located on the top end wall of the forward canister. These measurement locations were selected so that crude temperature differences could be constructed from the raw temperature data under the assumption of axisymmetric heat transfer. This assumption can not be formally established, but the transfer of momentum within the liquid is axisymmetric for the liquid spin-up process. The working temperature of the epoxy in which the thermistor beads were mounted was 260^{o}C. Figure 4 shows the temperature measurement principle used with the thermistors on board the projectiles. The natural logarithm of the resistance of a thermistor is inversely proportional to temperature. A simple voltage divider network related the voltage drop across the thermistor to its resistance and, hence, to temperature. The resistance of each thermistor is calibrated as a function of temperature prior to assembly in the canisters. A zener diode provides a stable reference voltage to the voltage divider network. Figure 5 shows a schematic of the thermistor/measurement/telemetry package installed on each projectile. All electronics are located in the ogive of the projectile. An electronic commutator sampled each thermistor position 10 times a second. This commutated signal modulated a voltage controlled oscillator (VCO or subcarrier oscillator) which, in turn, frequency modulated a crystal-controlled transmitter. The vertical dashed line in Figure 5 represents an electrical connector that provides continuity between the thermistors in the canisters and the electronics in the ogive. This connector is shown in Figure 6.

B. Field Test Equipment

The flight tests were conducted on the German Village range at DPG. A ground receiving station was set-up by DPG personnel. Other supporting equipment included an infrared time-zero system and a muzzle chronograph. An M110A2 howitzer with a standard muzzle brake was used. All projectiles were conditioned to 62^{o}C and fired at a quadrant elevation of 60 degrees. The Zone 9 propellent was conditioned to produce a 15% increase in pressure, except for BRL 1322 which was launched with a standard propellant temperature. Table 1 gives a round-by-round summary of the firing program in the actual firing order.

TABLE 1. ROUND-BY-ROUND SUMMARY[1]

Projectile Number[2]	Simulant Types and Mass (kg)	Muzzle Velocity[3] (m/s)	Time of Flight[4] (s)	Operational Temperature Positions	Comments
1322	NM - 1.31 TEP/DBA/EA - 6.71 AK 125 - 0.67	761.3	100.3	2 through 10	Last 5 seconds of flight data lost.
1323	NM - 1.31 TIP - 6.67	765.1	----	----	No zener reference voltage-no data.
1326	NM - 1.50 TEP/DBA/EA - 6.71 AK125 - 0.67	792.8	103.6	2,3,5,6	Zener reference lost during last 3 seconds.
1324	NM - 1.31 TEP/DBA/EA - 6.71 AK125 - 0.67	796.6	106.0	2,4,5,6,7,10	Zener reference lost during last 3 seconds.
1325	NM - 1.31 TIP - 6.67	797.2	----	----	Ground connection lost-no data.
1321	NM - 1.31 TIP - 6.67	798.1	----	6,7,9,10	Tape recorder malfunction lost first 27 seconds of data.

[1] Presented in firing order.

[2] Projectile number and BRL number are synonomous.

[3] Raw data from muzzle chronograph.

[4] Determined from telemetry and gun time zero data.

IV. TEMPERATURE DATA

Data were obtained from only four of six projectiles. Positions T1, T2, and T3 are located in the rear canister. Positions T5 and T6 are close to the rupture diaphragms, but they are located in the forward canister. All other positions are located in the forward end of the forward canister. Note that T5 and T6 are separated by over 35 cm (see Figure 3). The temperature data are usually presented on two time scales, and thermistors located at identical distances from the base of the canister are plotted on the same graph. Error bars are not presented on the plots, but a detailed discussion of errors in amplitude and phase are presented in Appendix A. In general, the amplitude resolution is ±20°C for temperatures over 300°C and ±5°C for substantially lower temperatures. Phase resolution, i.e. time delay, is unknown due to the effects of the variable rotation state of the simulants and the heat sink effect of the canisters.

Round 1322 (TEP/DBA/EA-NM)

Position T1 was the only thermistor not providing data for this round. The data for all other positions are shown in Figures 7-15. Figure 7 shows the data for T2 and T3. The data for T2 indicated a steady temperature of 80-90°C down-range, while the data for T3 were approximately 170-180°C. Figure 8 showed a rapid rise to 90°C for T2 and then a slight decay, while T3 had a monotonic rise in temperature. Unusual temperature behavior was noted at approximately 50s for T3 with no interpretation. Figure 9 gives the data for T4 and T5. A steady temperature of 160°C was recorded for T4, while T5 rose steadily to a temperature of 320°C. Figure 10 shows a monotonic increase in temperature for both T4 and T5. Figure 11 gives the data for T6 and T7. A steady temperature of 190-200°C was recorded for T7, while the down-range data for T6 indicate a slowly increasing temperature in excess of 300°C. Figure 12 shows a similar rise in temperature for both sensors until approximately 2s, where T6 continued to increase and T7 decayed. Figure 13 gives the data for T8 and T9. T8 had a steady state temperature of approximately 150°C, while T9 indicated a steady temperature of approximately 210°C with an increasing trend near the end of the trajectory. Figure 14 shows the details of the early data, where both sensors were of similar temperature for only one second. Figure 15 shows the data for T10, which did not function past 25s into the flight.

Round 1326 (TEP/DBA/EA-NM)

Positions 1, 4, 9, and 10 did not yield useable data for this round. Figures 16-22 provide the data. Figure 16 shows the behavior of T2 and T3. Both sensors rose to 100°C in less than 1s, but T2 decayed to a steady temperature of 80-90°C, while T3 increased to over 200°C in about 3s. T3 decayed slowly and produced unrealistic temperatures beyond 60s. Hence, it is possible that T3 or its circuitry were damaged. No data were obtained for T2 between 3 and 17 seconds. Figure 18

shows the data for T5, with an expanded time scale in Figure 19. A monotonic rise in temperature was recorded, with unusual behavior beyond 60s similar to T3. T6 behavior is shown in Figures 20 and 21. A steady temperature in the vicinity of 300° C was recorded, but again no useable data were obtained past 60s. Figure 22 gives the temperature data for T8. Only 2s of data were obtained.

Round 1324 (TEP/DBA/EA-NM)

Positions 1, 3, 7, 8, and 9 did not provide any data for this round. Figures 23-29 give the temperature data for BRL 1324. Figure 23 shows the T2 temperature history, where a rapid rise to almost 100°C was followed by a rapid decay to below 80°C and then a steady growth back to 100°C. Figure 24 shows an expanded time scale for this data. Figure 25 shows the data for T4 and T5. T4 achieved a steady temperature of about 200°C, while T5 climbed well above 300°C. Figure 26 gives an expanded time scale for the T4 and T5 data. Figure 27 provides the data for T6 and T7. T7 functioned for only 11s (Figure 28), but realized a temperature of almost 200°C. T6 on the other hand, reported temperatures in excess of 360°C. Figure 29 gives the data for T10, which only functioned for 25s and achieved a temperature of 250°C.

Round 1321 (TIP-NM)

Very little information was obtained from this projectile with only four positions, T6, T7, T9 and T10, functioning. Data were not recorded prior to 27s due to a tape recorder malfunction. Figure 30 shows the data for T6 and T7. An unusual rise in temperature was indicated at approximately 60s, but since T7 failed at 70s these data are suspect. Figure 31 shows the data for T9 and T10. Although T9 did not show any unusual behavior in the 60s time-frame, T10 failed at 54s.

V. DISCUSSION

The most obvious and important effect shown by these series of tests was the very high temperatures consistently measured at the T5 and T6 positions (the 1½ inch protrusion positions) for the TEP loaded projectiles.* The highest temperature previously measured was 247°C at a flight time of 62s using a similar thermistor and mount for BRL 978, which was tested in September of 1976.** It was not anticipated that temperatures in the range of 350°C would be encountered when the projectiles were conditioned to 62°C with flight times of 100s. High temperature data from three different projectiles and from two positions separated by 35cm indicate that the reaction temperatures are much higher than previously suspected. BRL 1326 contained a higher mass of NM than

**See Table 1 for a specification of the various simulants.*
***See Appendix B for a tabular data listing.*

either BRL 1322 or BRL 1324, and theoretically should have yielded higher temperatures. This is not evident from the measurements. If one assumes that the strength of the simulant reaction is dependent upon the amount of NM and the launch velocity, then the time to reach a high temperature, say 300°C, should be shortest for BRL 1326 and longest for BRL 1322. An examination of positions T5 and T6 for the TEP rounds is consistent with this concept. The temperatures should be lower for a TIP-NM reaction than for a TEP-NM reaction, and this is supported by the data from BRL 1321.

At shot exit most of the thermistors were reporting temperatures that were very close to the conditioning temperature of 62°C, hence initially these thermistors and the calibration data were producing proper results. However, three pathological problems did occur with the electronics (see Table 1). Payload conditioning produced the failure of some zener diodes. This can be avoided by the use of solid state voltage regulators. Second, the ground connection for the divider network was lost. This is particularly frustrating since redundant positions on the electrical connector were used. This problem is perhaps unavoidable due to the Charge 9 launch conditions. Third, no T1 thermistors functioned, and they were probably destroyed by the burst discs.

A slightly closer look into the temperature data is valuable. Most of the short protrusion gages indicated an initial rapid rise in temperature followed by a sharp decay. The decay was more pronounced for a flush mounted thermistor than for other types. It is possible that this is a heat sink effect produced by the canister, or it is also possible that the cooler fluid is being circulated over the sensor by the spin-up process. Note that the brass mounts were not insulated from the canister wall, but the thermistors are suspended in epoxy within the brass shank and not in intimate contact with the brass mount. For the flush mounted thermistors it is probable that the temperature of the fluid was initially sensed, but subsequently the temperature of the canister wall dominated the temperature of the thermistor.

The on-board reaction is a very complicated one, but the application of a simple heat conduction analogy can be helpful. Let q be the heat flux and k be the thermal conductivity of the spinning liquid in the radial direction. Then approximate the thermal gradient in the radial direction by a simple difference:

$$q = -k(\Delta T/\Delta r).$$

Further, if it is assumed that the thermal conductivity is a constant and that heat transfer is axisymmetric, then the temperature differences at stations of identical longitudinal position could be used to determine a relative magnitude or variation in the heat flux. The temperature differences for BRL 1322 are provided in Figures 32-35. These data represent the temperature gradient across an annulus of fluid defined by

the difference in the depths of the pertinent thermistors. Figure 32 shows the temperature difference T3 - T2 reached a peak value of 110°C at approximately 20s with a slow decay for the remainder of the flight. The temperature difference T5 - T4 is shown in Figure 33, and this difference never reached a steady value. Temperature differences at the forward end of the top canister were substantially lower and indicated steady levels very early in flight until late flight times (Figures 34 and 35). The presence of radial temperature gradients makes interpretation of these differences difficult. The distance between T9 and T8 is only ½ inch while the distance between T7 and T6 or T5 and T4 is 1 inch. A canister with only combinations of 1½ and ½ inch mounts may help resolve this difficulty. An estimate of the heat flux would also require the variation of the thermal conductivity with temperature, which is not available. Note that if these flights had not been longer than 60s and if long intrusion depths were not used, one would be tempted to conclude that the temperature differences were steady. The data in Figure 33 show that the temperature differences are not steady. Temperature differences for other rounds do not add any further insight since only a few thermistors were functioning.

The data presented within this report do not clearly indicate a mechanism for the down-range base failure mode. The temperature of the canister is well approximated by the temperature of the flush mounted thermistors and could be used to estimate thermal expansion in the longitudinal direction and any resulting stresses that could be applied to the base. Measurement of pressure would also be useful to determine loads on the base. Figure 35 shows pressure data presented in Reference 1 for TEP loaded canisters. Position 5 was located in the outer wall of the canister approximately 6cm from the top of the canister, while position 7 was located at the center of the top end wall of the forward canister. A 750 psi peak pressure was measured with a sharp decay. This decay was attributed to leakage between the two canisters since only tack welds were used to prevent differential rotation between the canisters. These pressures are far below the 4000 psi required for base separation of an undamaged base, i.e., one that has not been fired at Charge 9. These data in Figure 35 were not at the launch conditions of interest, however, and the nature of the high pressures that may accompany the 350°C temperatures is unknown.

VI. CONCLUSIONS

Payload temperatures in the range of 350°C were measured on-board the XM736 projectile. The projectile was loaded with reactive simulants conditioned to 62°C, and fired at velocities producing 100s flight times. Temperature differences based upon these data indicate thermal gradients that are increasing over the entire flight history. The consequences of these very high and unexpected temperatures and base failure modes have not been established, and further testing with pressure and temperature sensors is recommended.

VII. ACKNOWLEDGEMENT

The author is indebted to Mr. John Watson who built the payload measurement systems, to Mr. W.H. Clay for his contributions to the text of Appendix A, and to Mr. C. Hughes who provided simple explanations of the various simulants and their reactions.

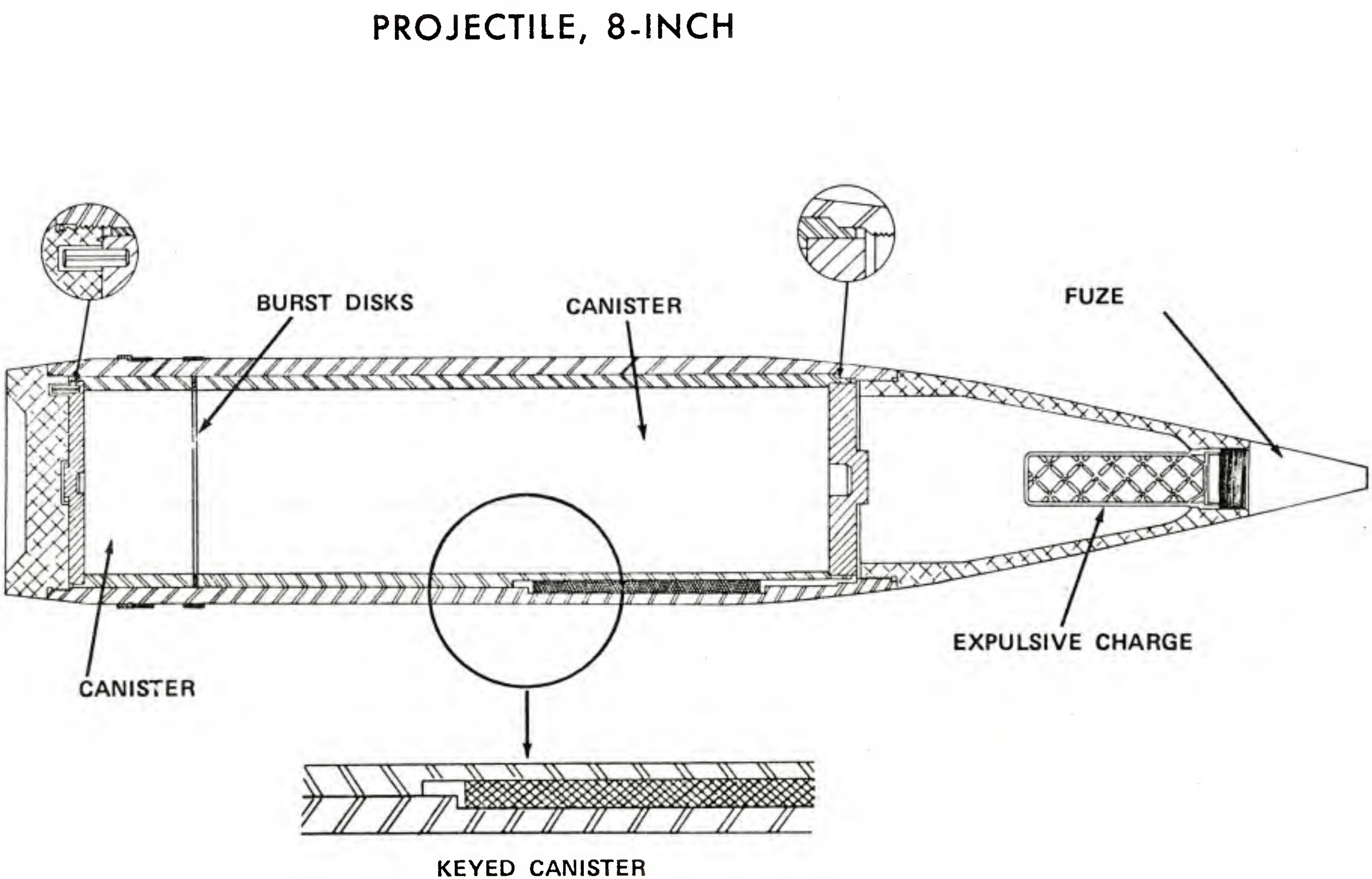


Figure 1. Cut-away view of a standard XM736 projectile, DT II hardware.

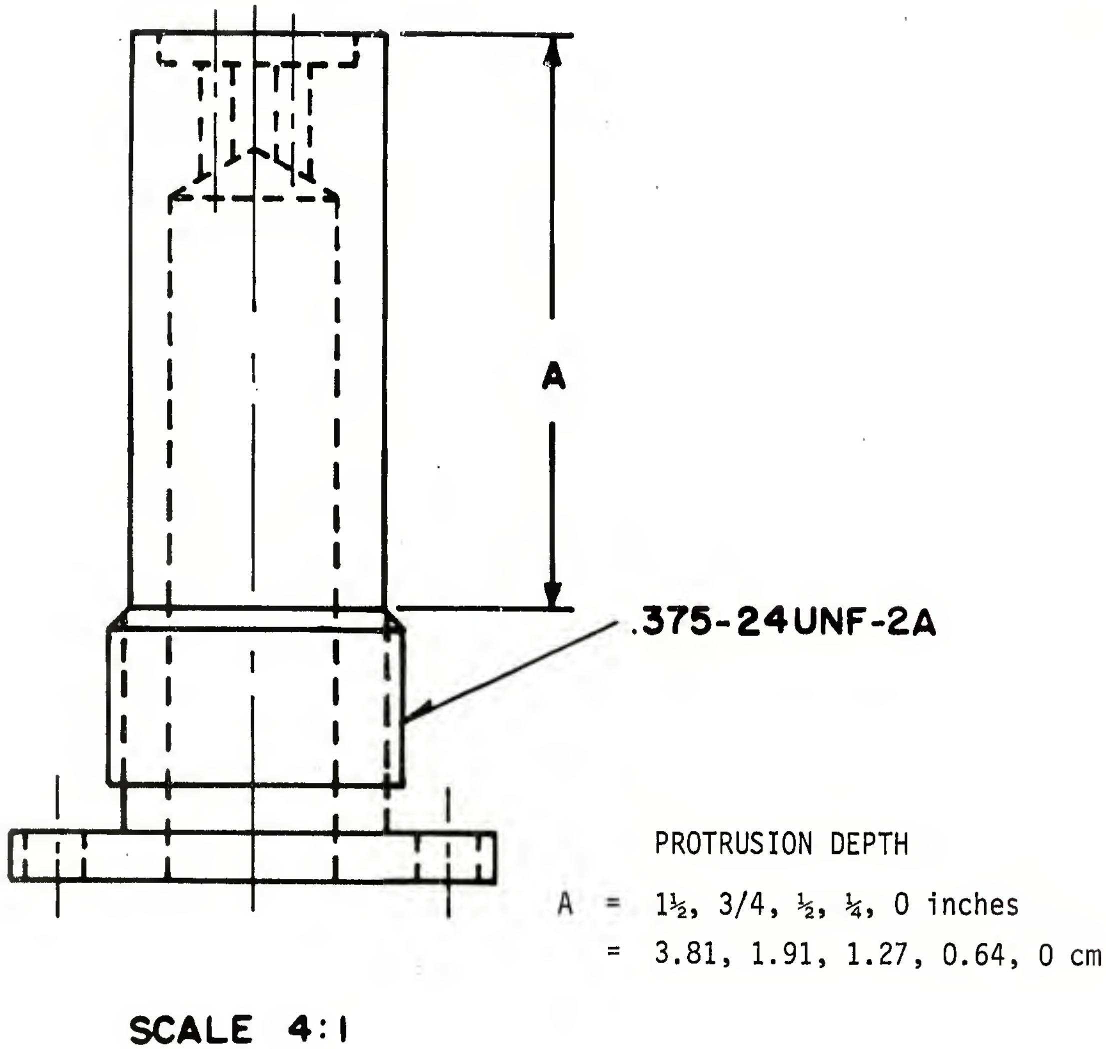


Figure 2. Thermistor mount.

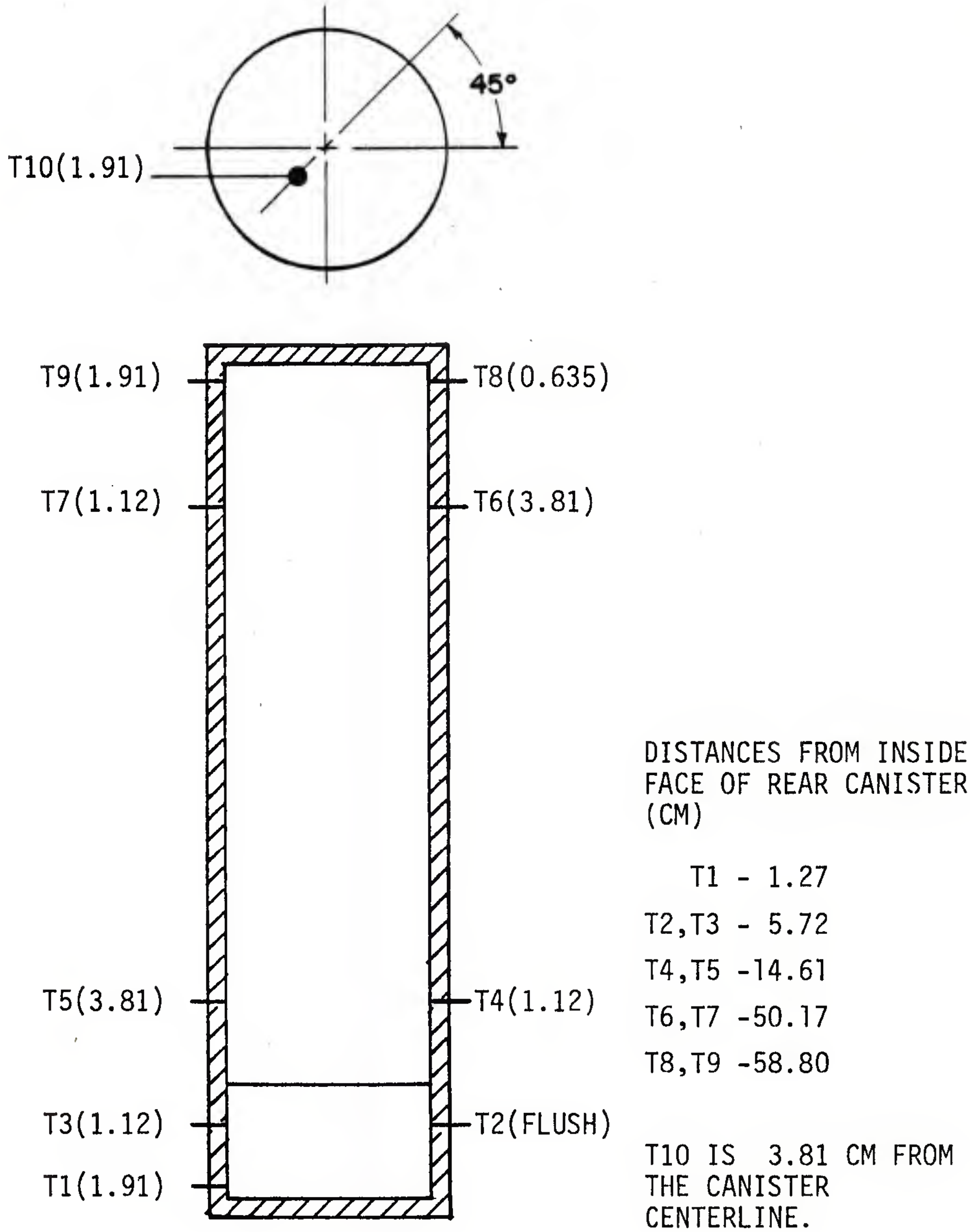


Figure 3. Thermistor locations.

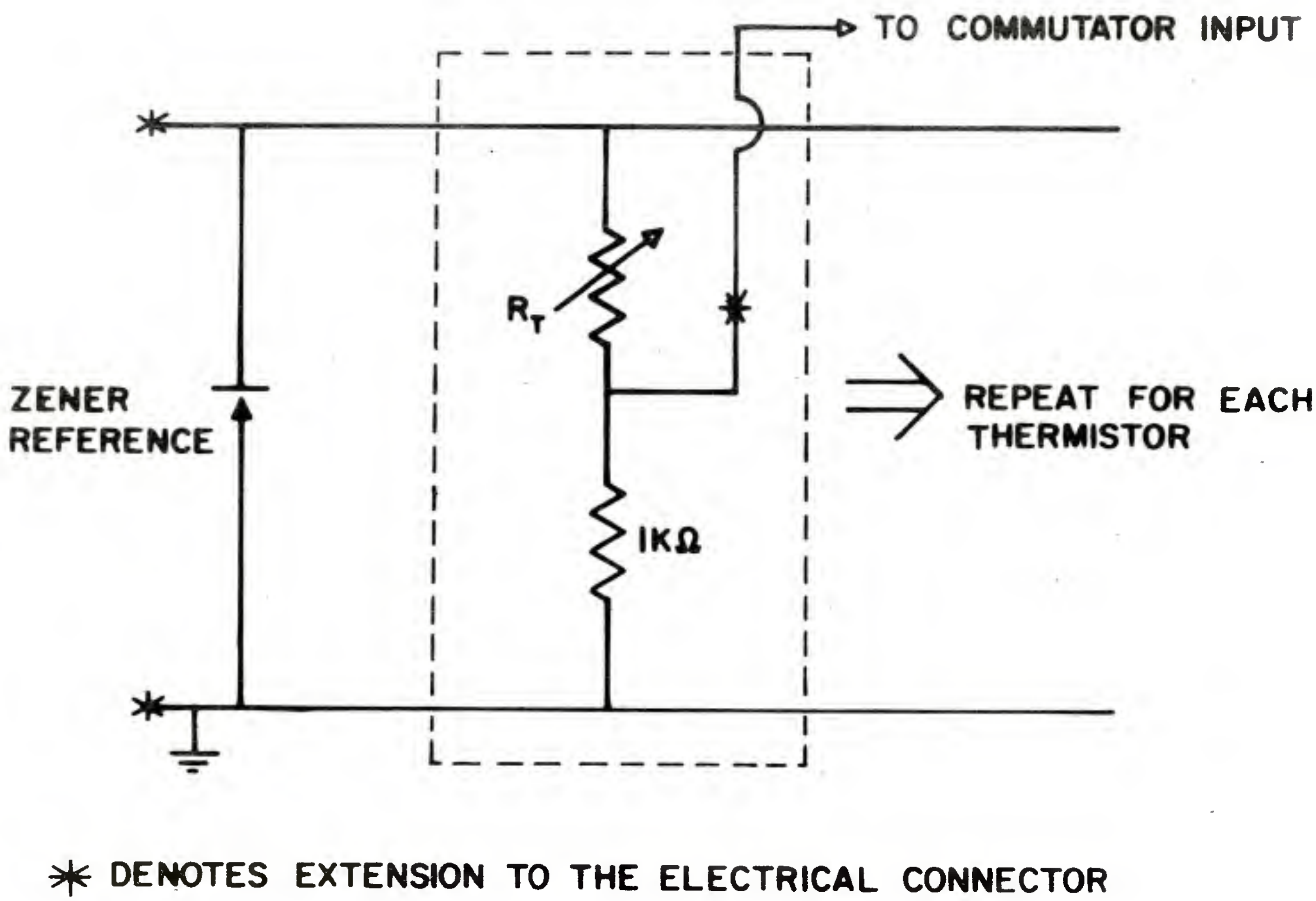


Figure 4. Temperature measurement circuit.

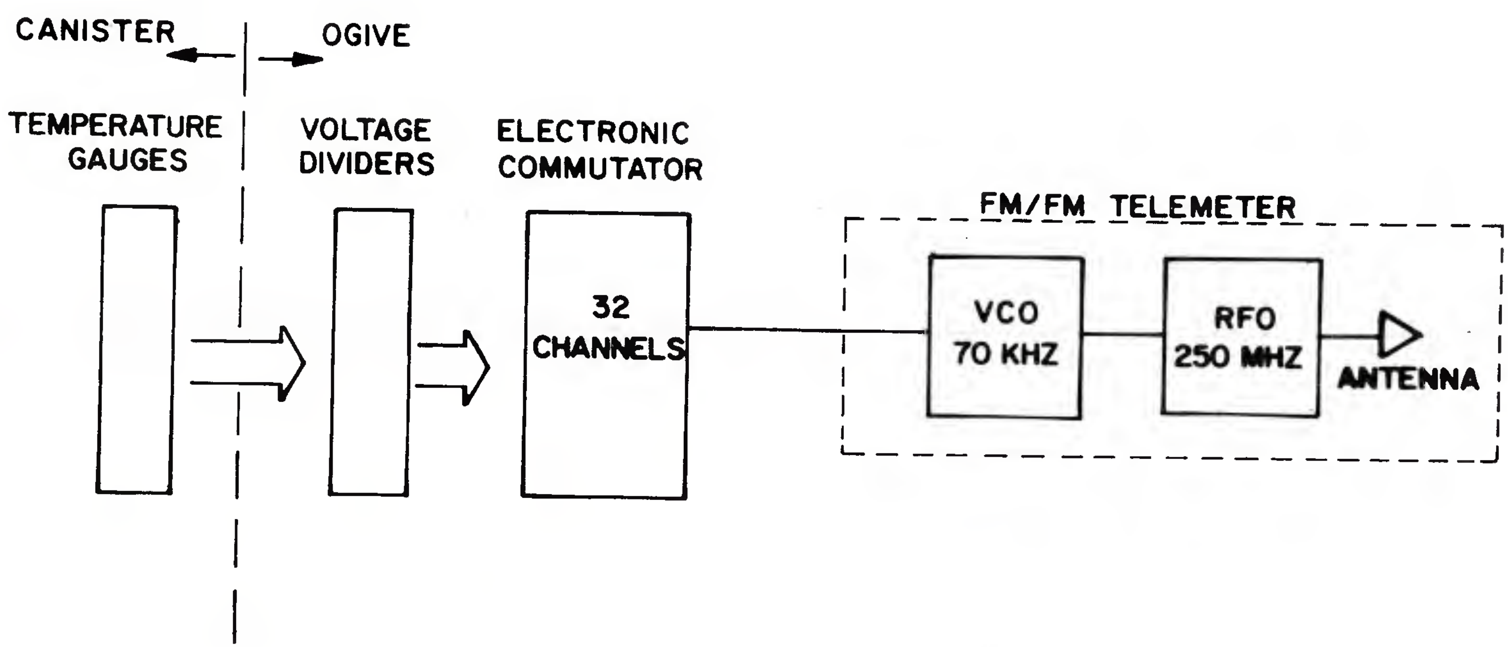
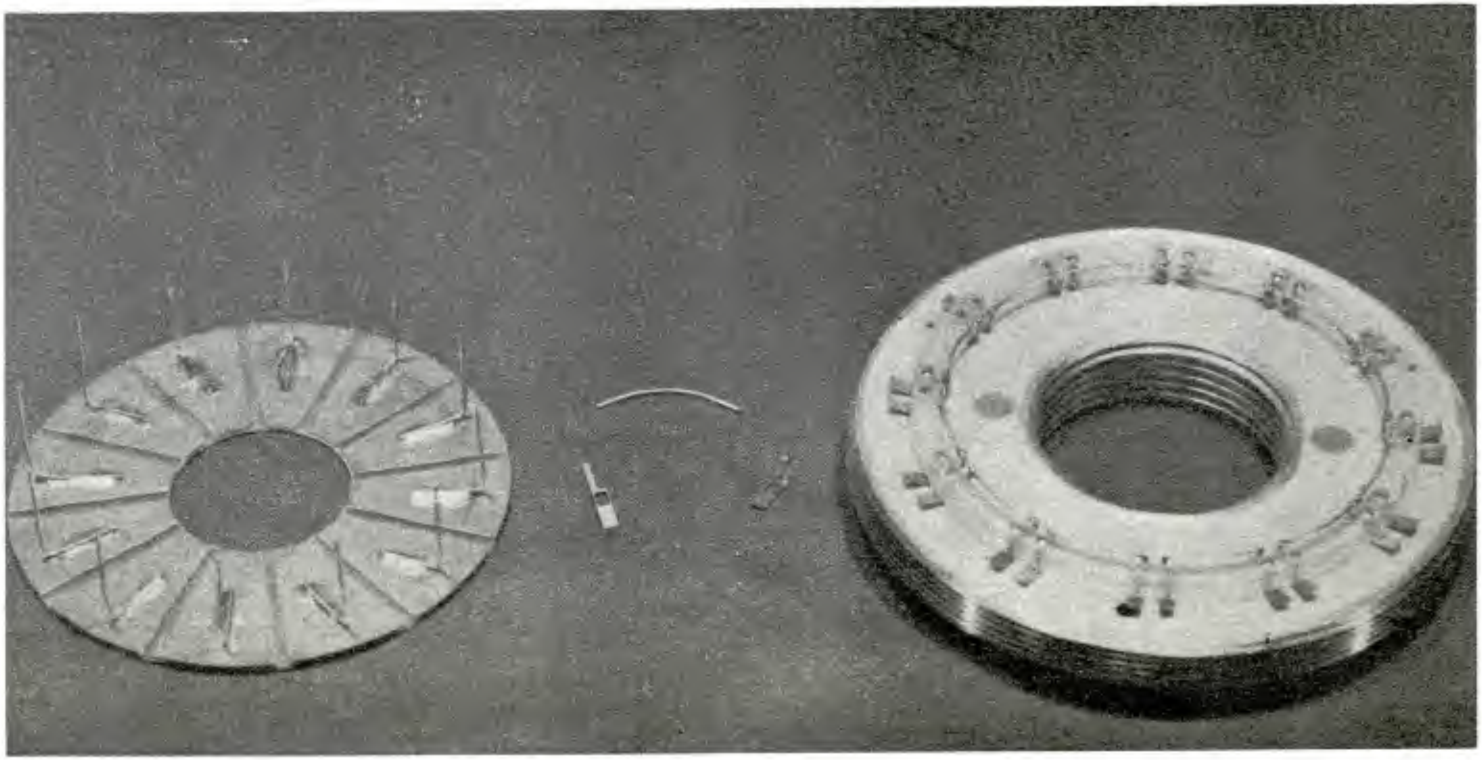


Figure 5. Schematic of temperature measurement/telemetry system.



MALE PART - CANISTER MOUNTED

FEMALE PART - OGIVE MOUNTED

Figure 6. Electrical connector.

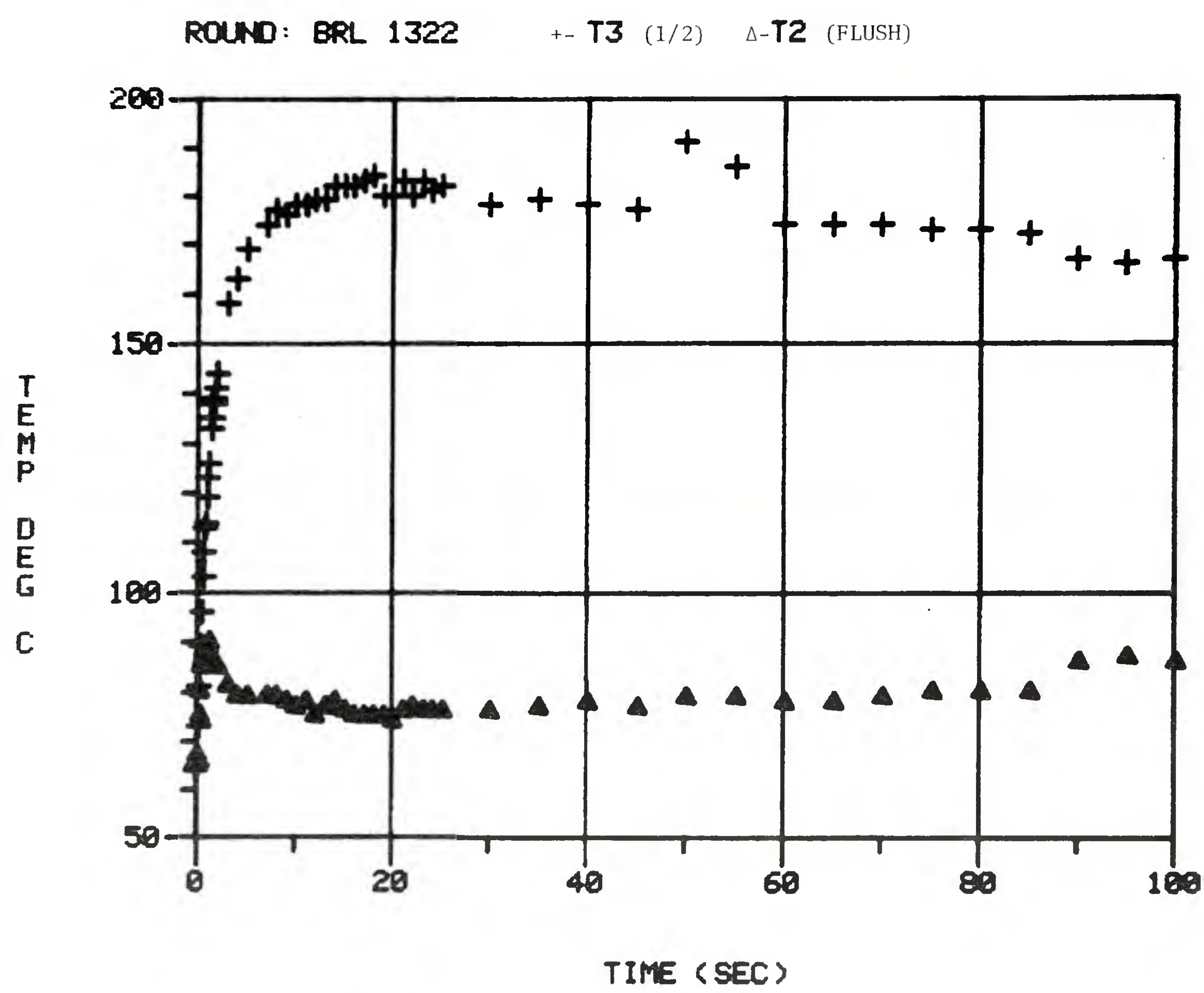


Figure 7. BRL 1322: Time versus Temperature for Positions 3 and 2 (0-100 s).

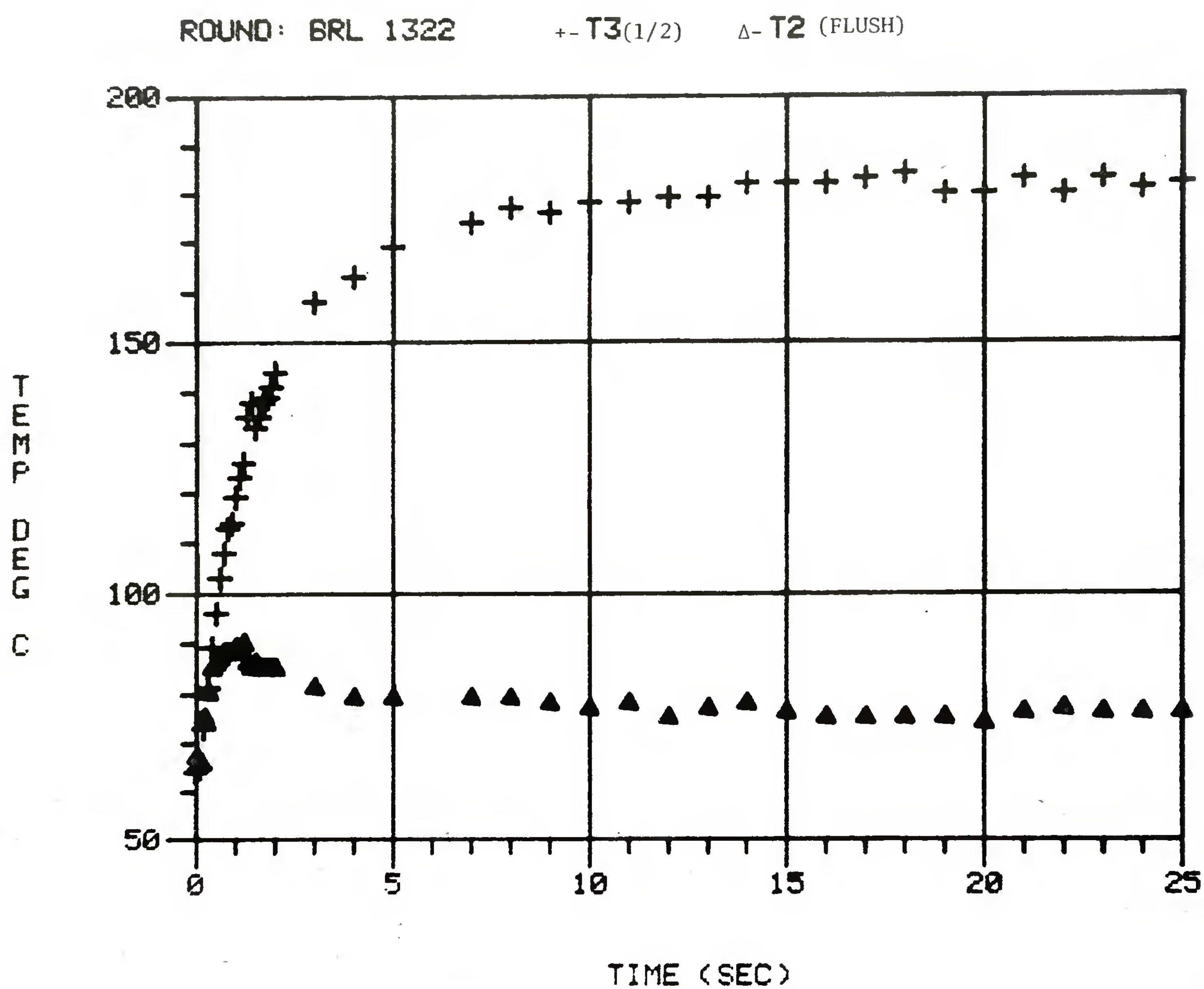


Figure 8. BRL 1322: Time versus Temperature for Positions 3 and 2 (0 - 25 s).

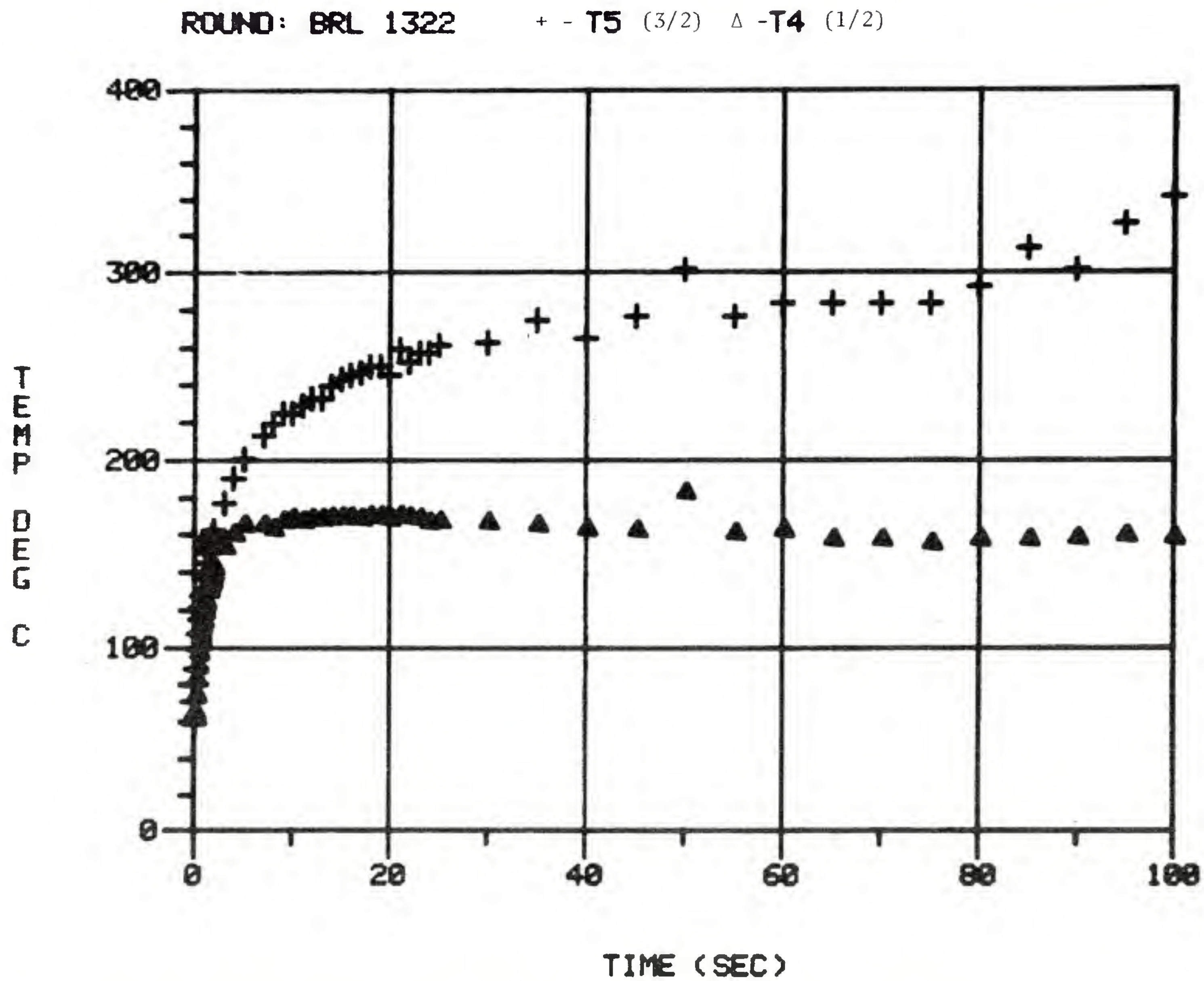


Figure 9. BRL 1322: Time versus Temperature for Positions 5 and 4 (0-100 s).

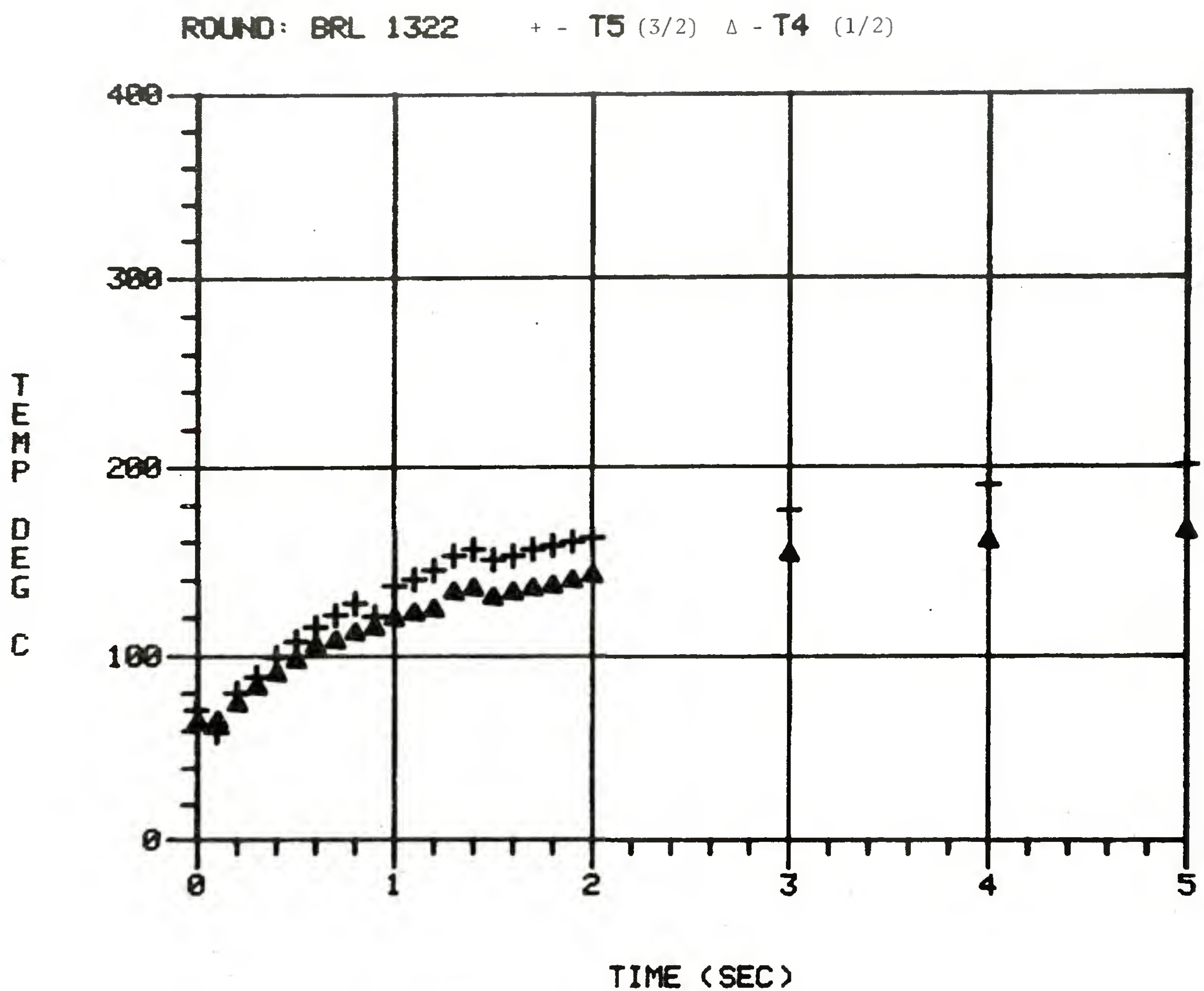


Figure 10. BRL 1322: Time versus Temperature for Positions 5 and 4 (0-5 s).

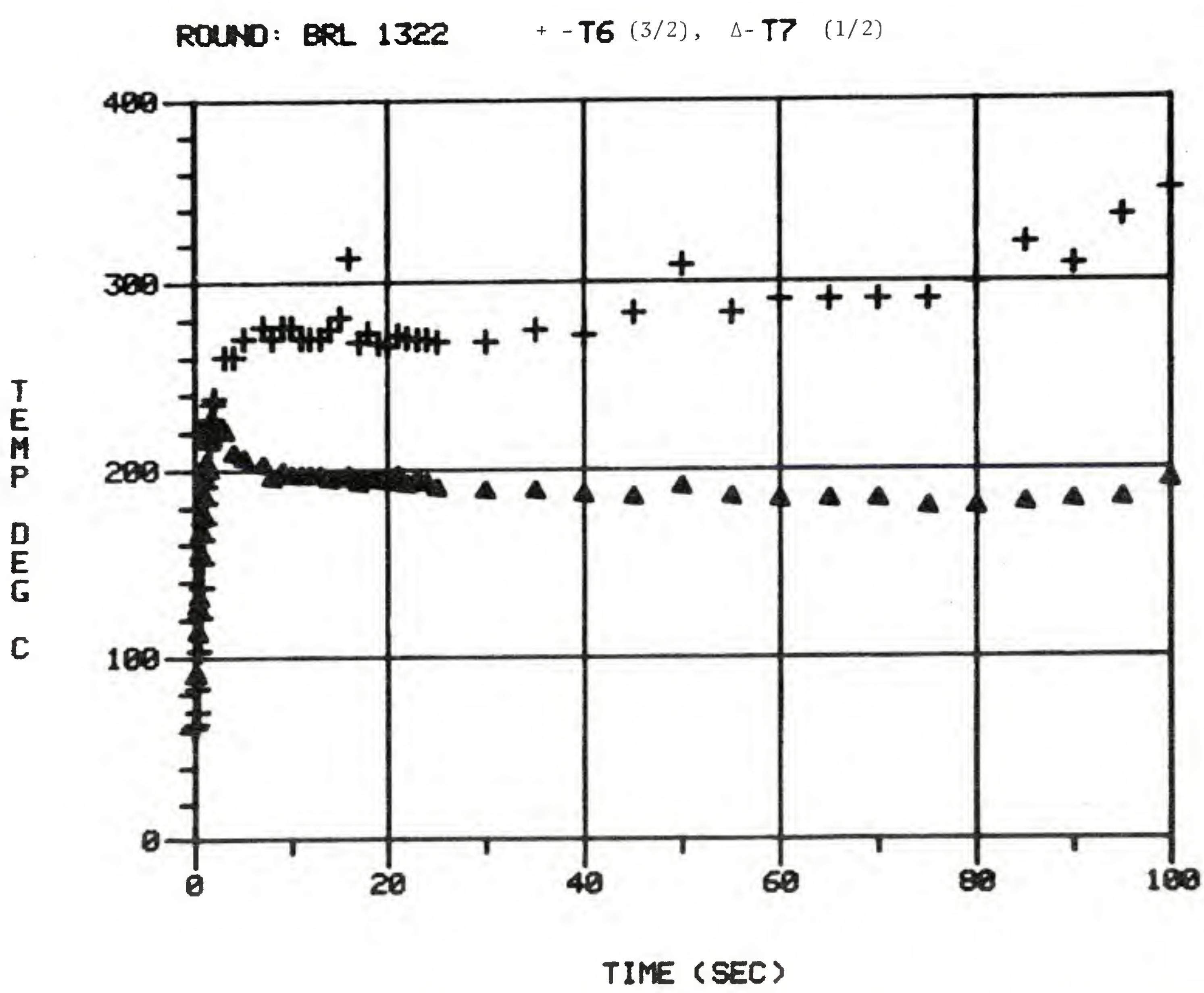


Figure 11. BRL 1322: Time versus Temperature for Positions 6 and 7 (0-100 s).

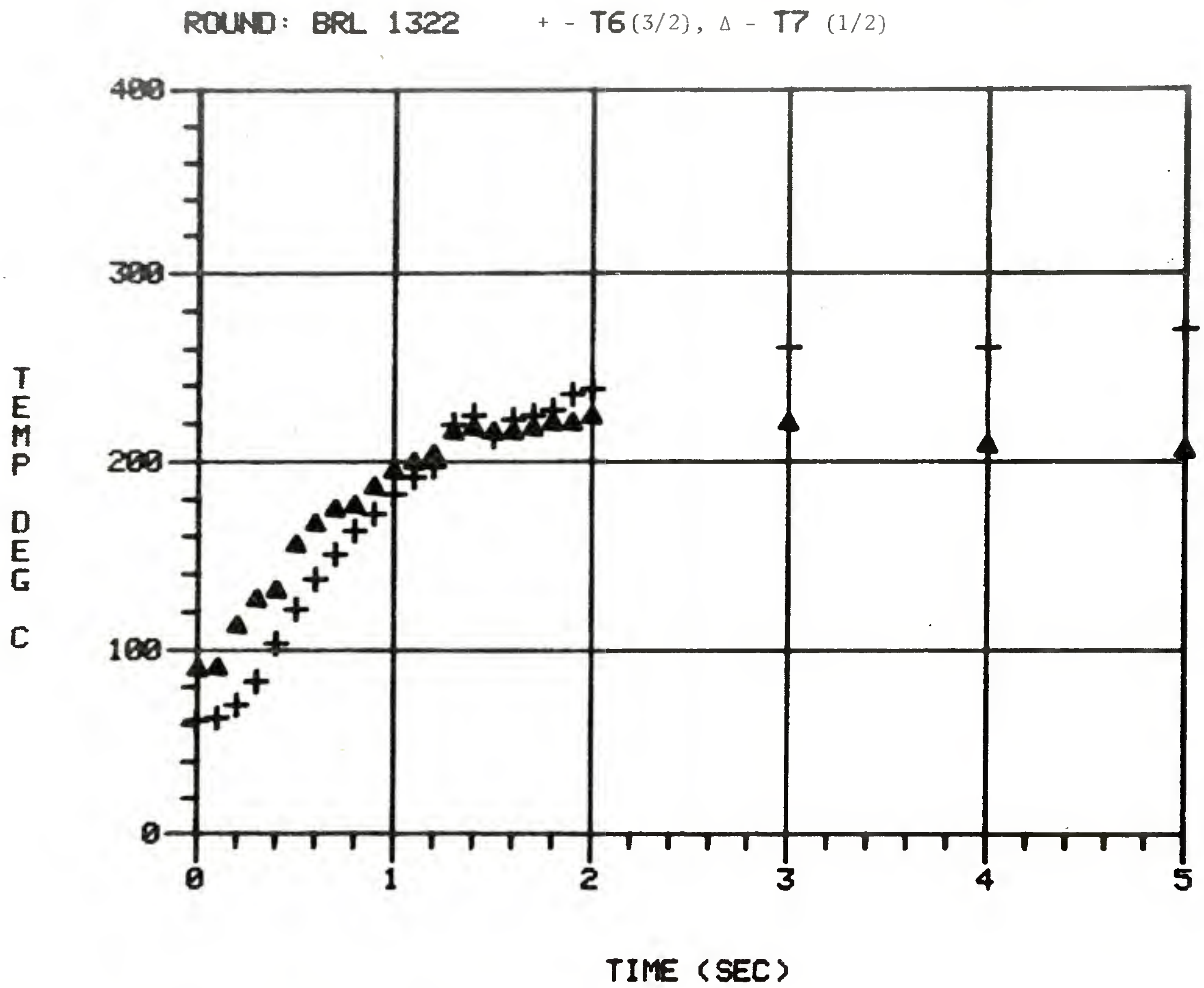


Figure 12. BRL 1322: Time versus Temperature for Positions 6 and 7 (0-5 s).

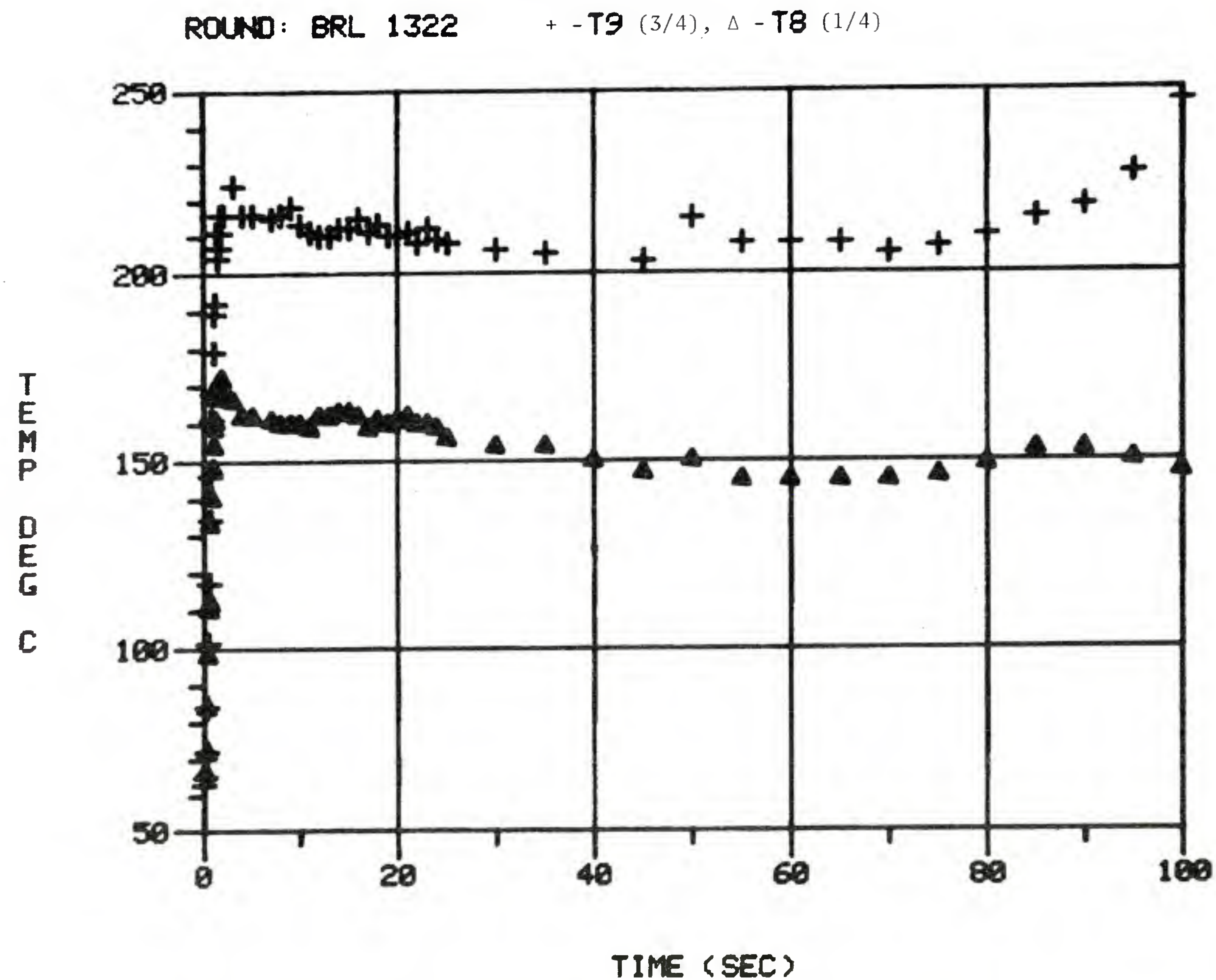


Figure 13. BRL 1322: Time versus Temperature for Positions 8 and 9 (0-100 s).

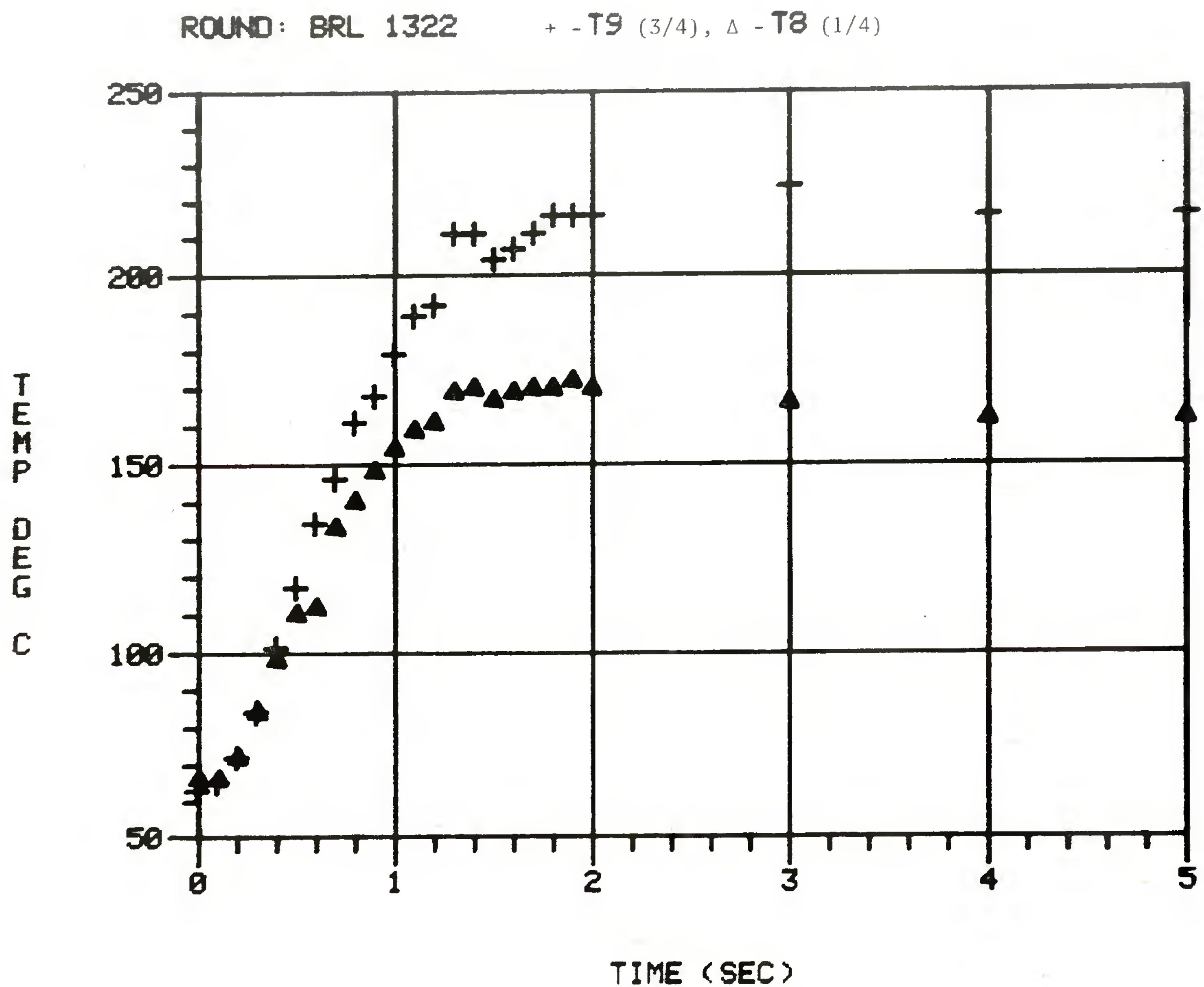


Figure 14. BRL 1322: Time versus Temperature for Positions 8 and 9 (0-5 s).

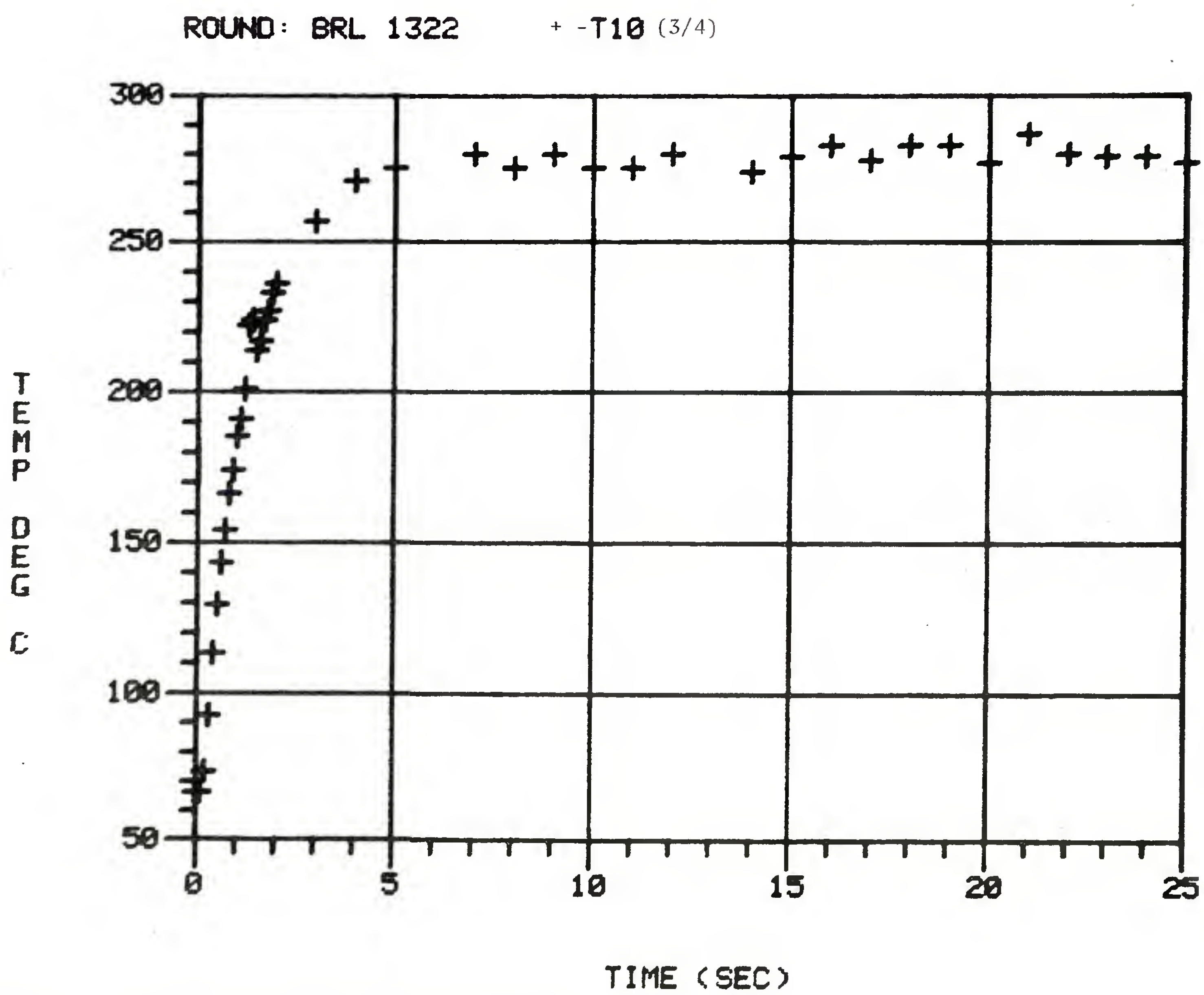


Figure 15. Time versus Temperature for Position 10 (0-25 s).

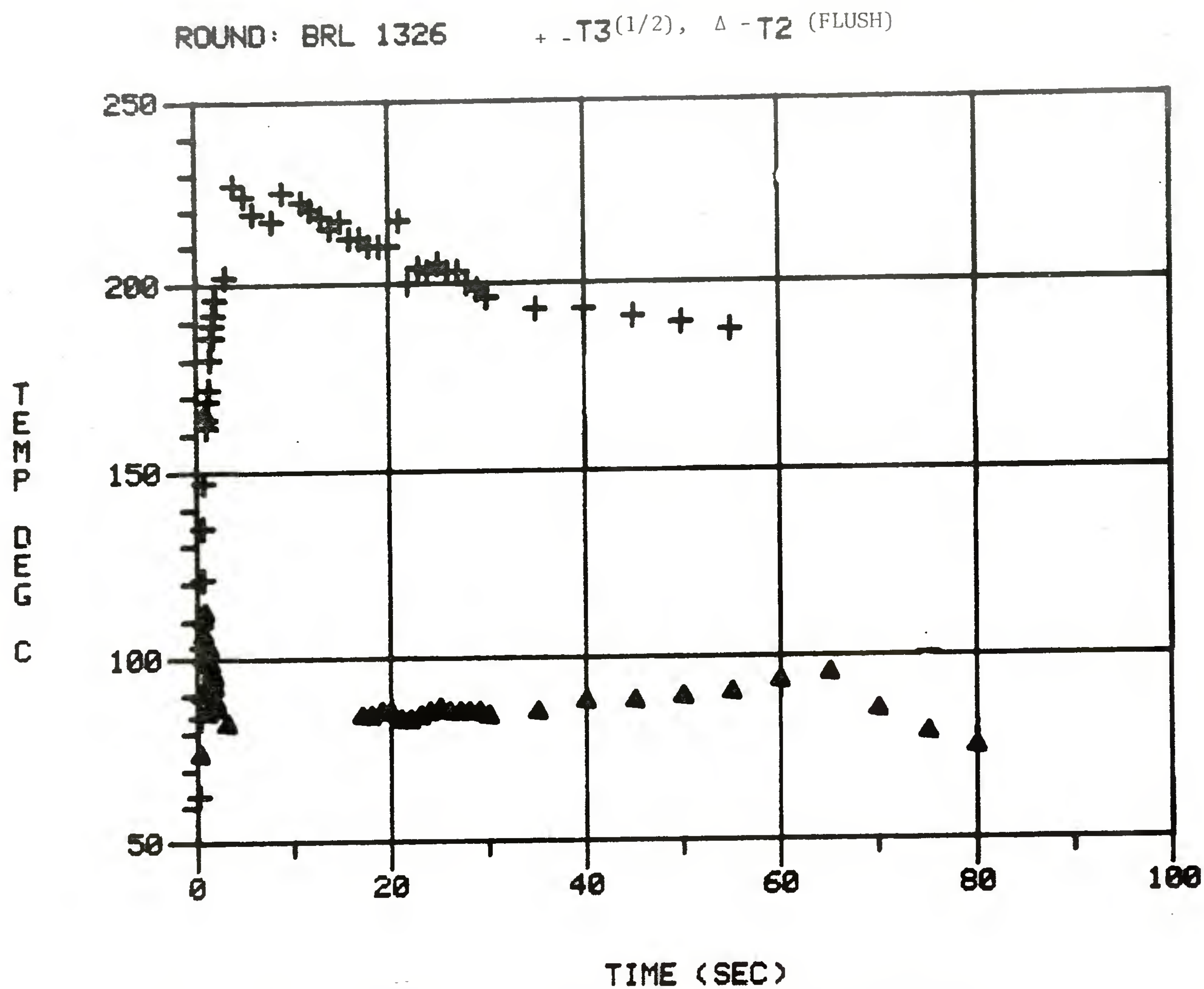


Figure 16. BRL 1326: Time versus Temperature for Position 2 and 3 (0-100 s).

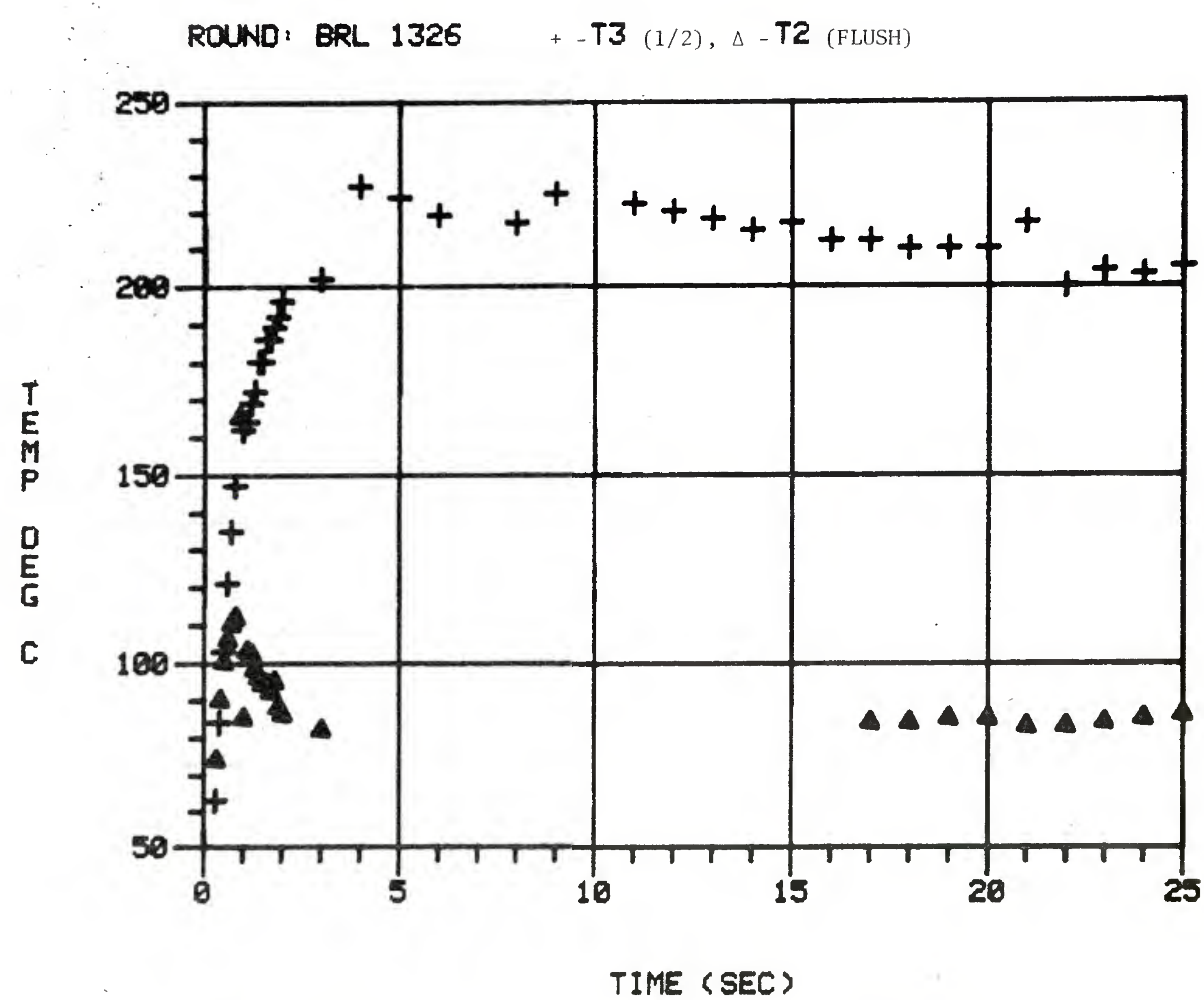


Figure 17. BRL 1326: Time versus Temperature for Positions 2 and 3 (0-25s).

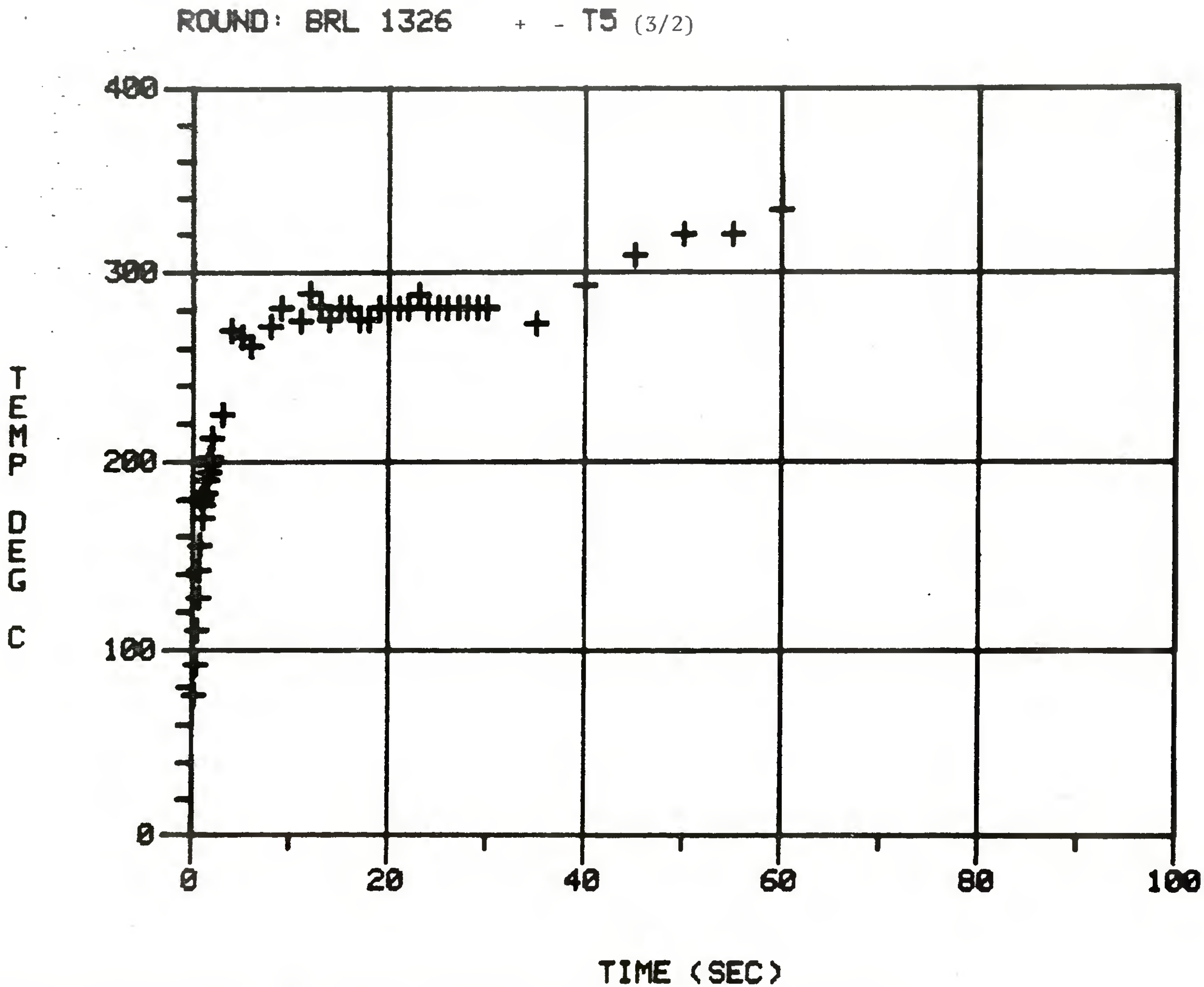


Figure 18. BRL 1326: Time versus Temperature for Position 5 (0-100 s).

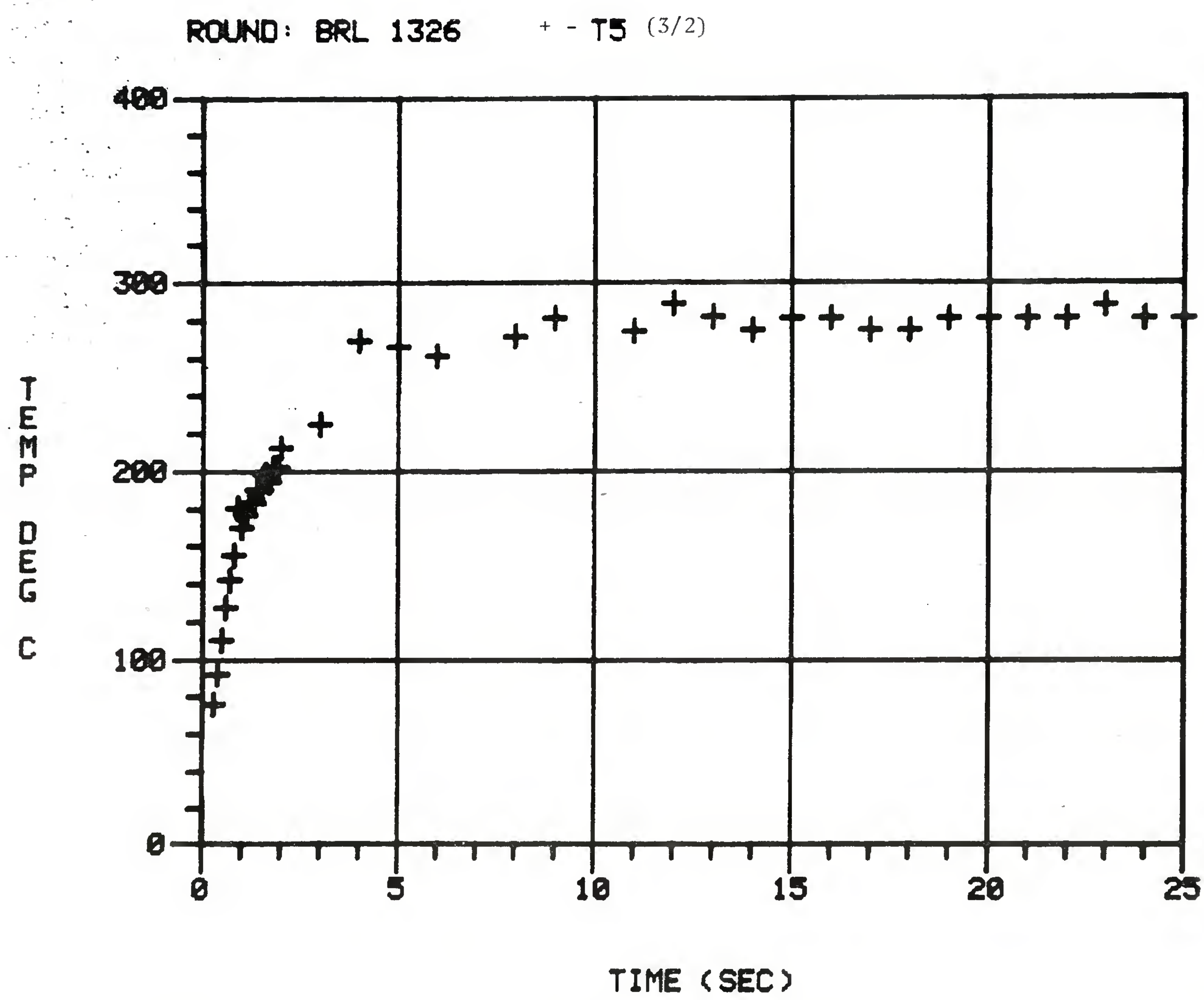


Figure 19. BRL 1326: Time versus Temperature for Position 5 (0-25 s).

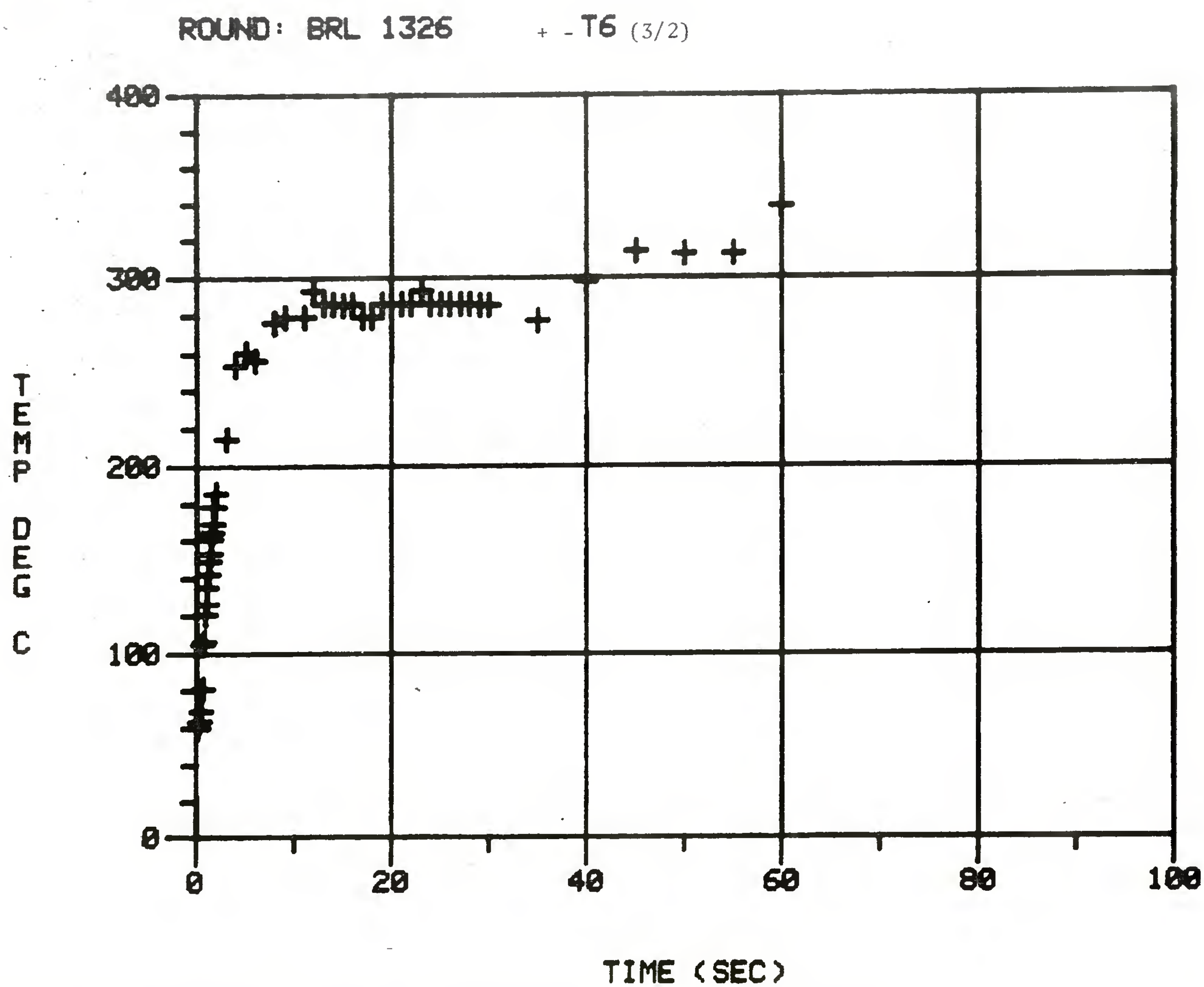


Figure 20. BRL 1326: Time versus Temperature for Position 6 (0-100 s).

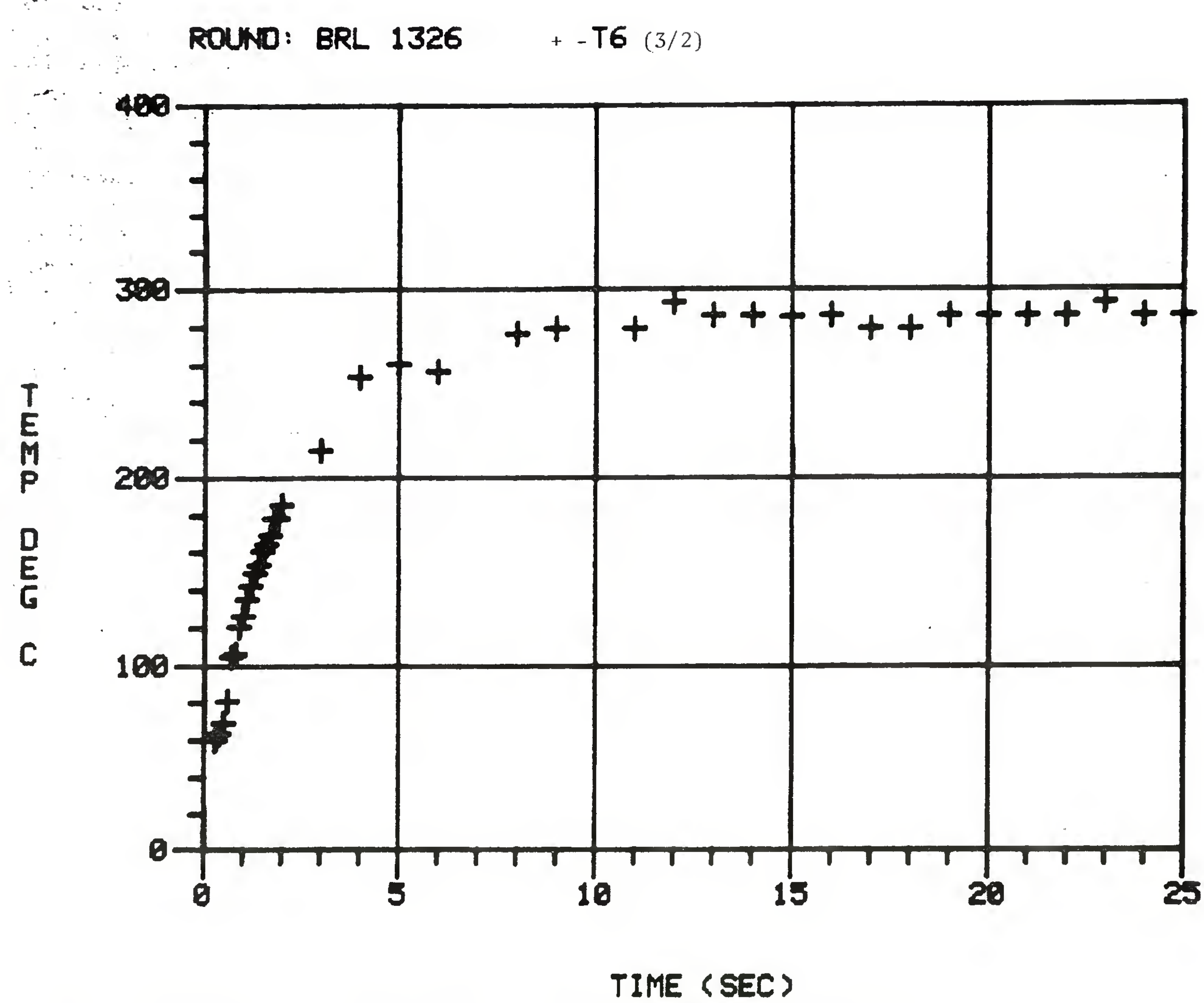


Figure 21. BRL 1326: Time versus Temperature for Position 6 (0-25 s).

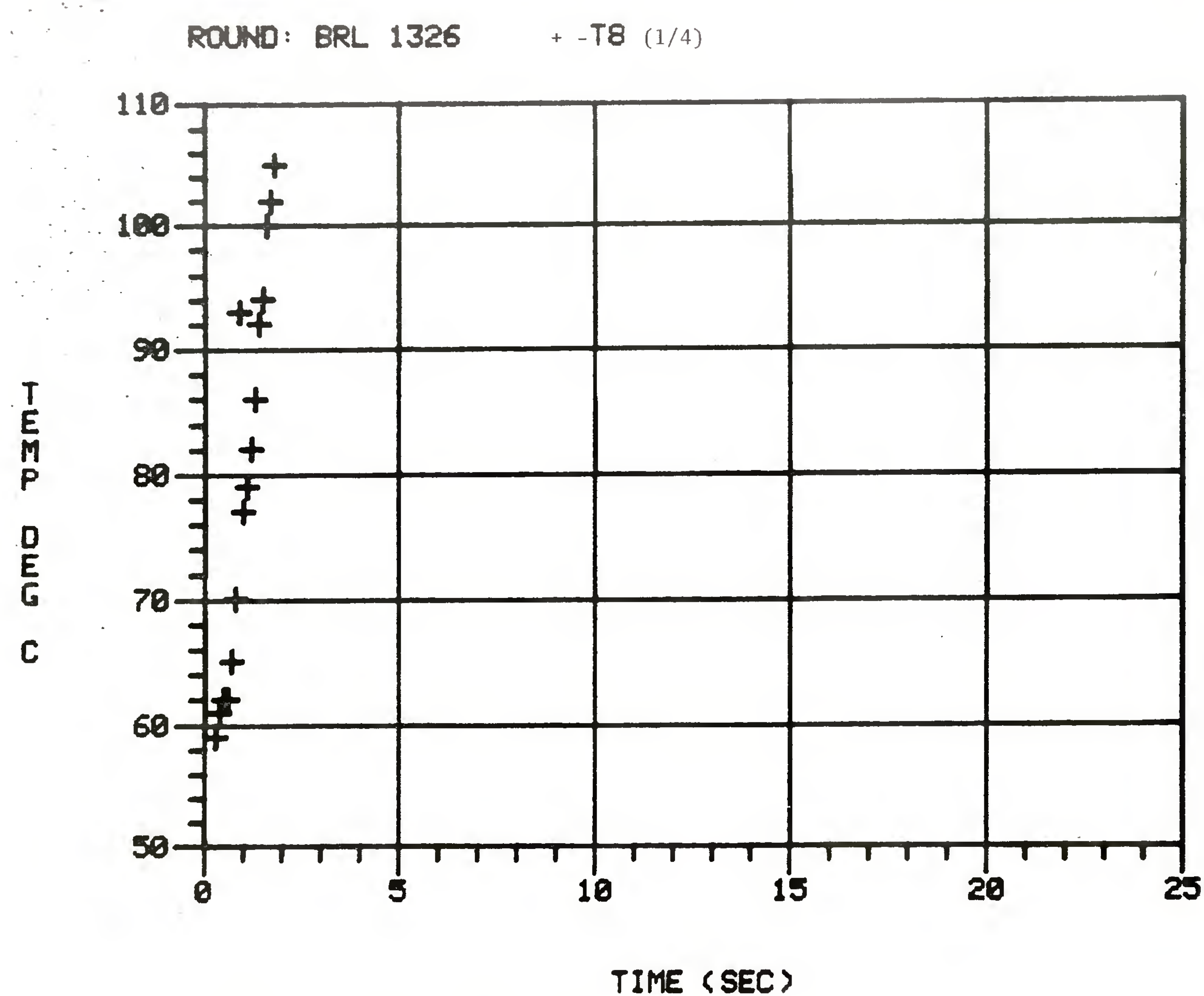


Figure 22. BRL 1326: Time versus Temperature for Position 8 (0-25 s).

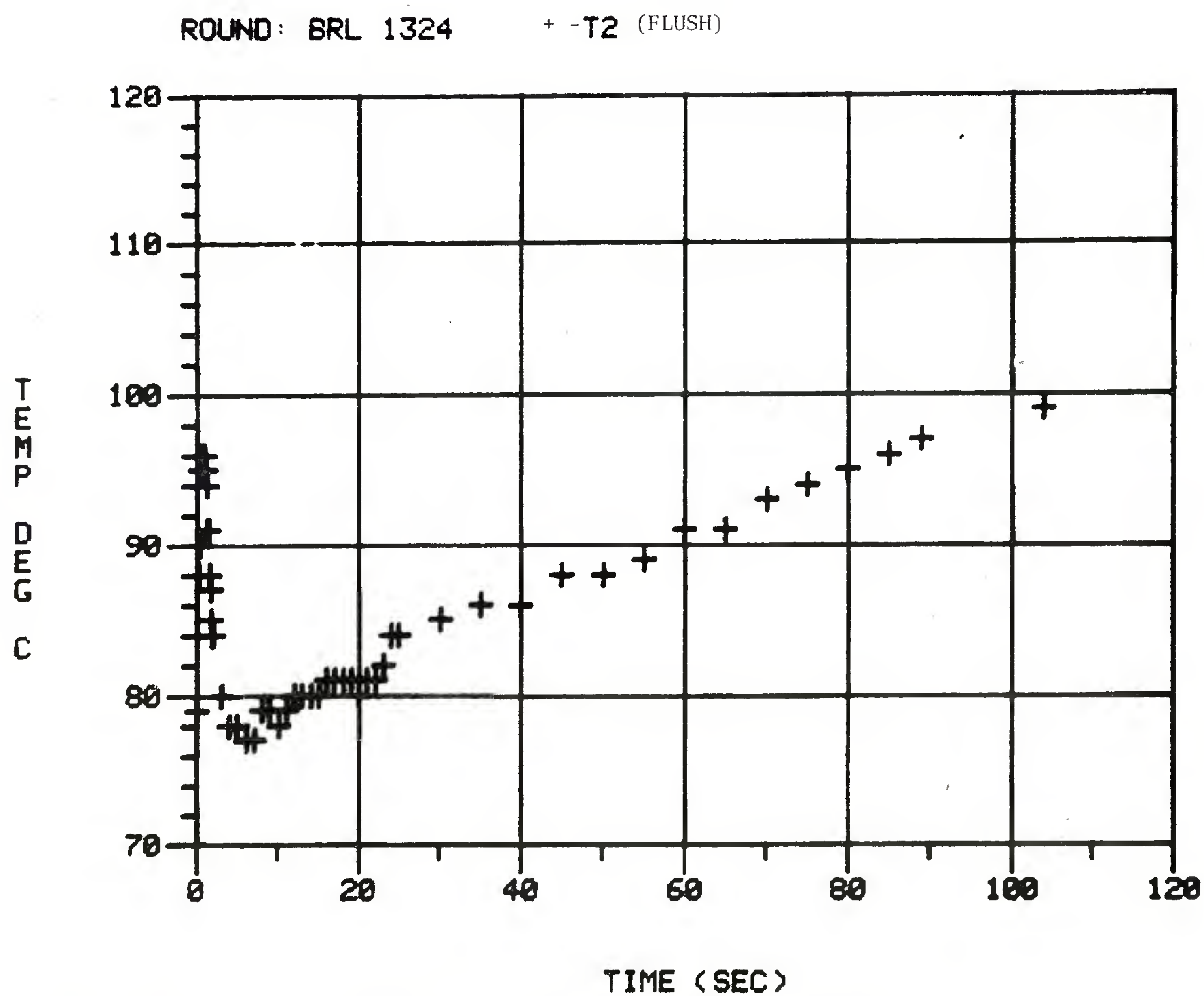


Figure 23. BRL 1324: Time versus Temperature for Position 2 (0-120 s).

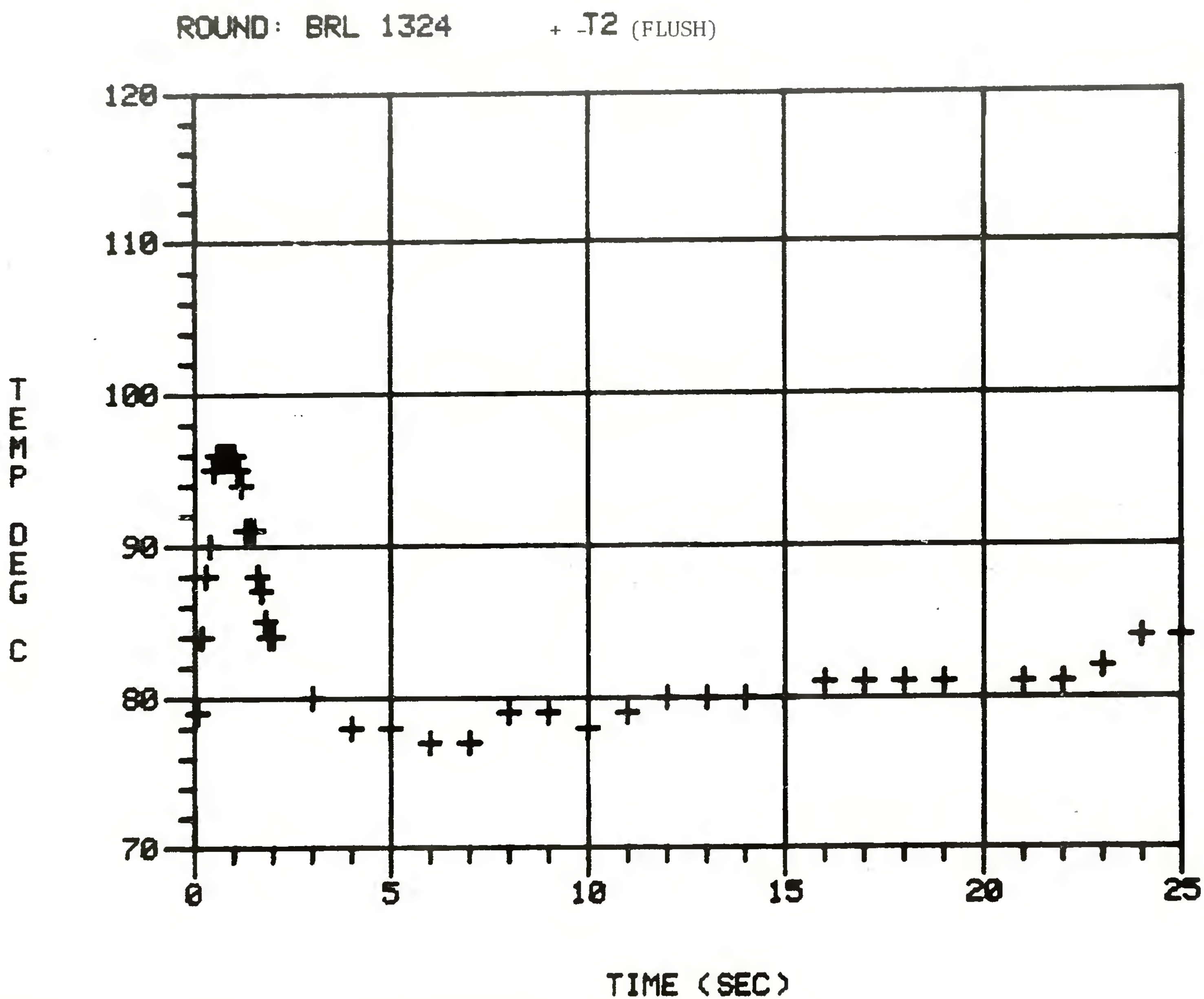


Figure 24. BRL 1324: Time versus Temperature for Position 2 (0-25 s).

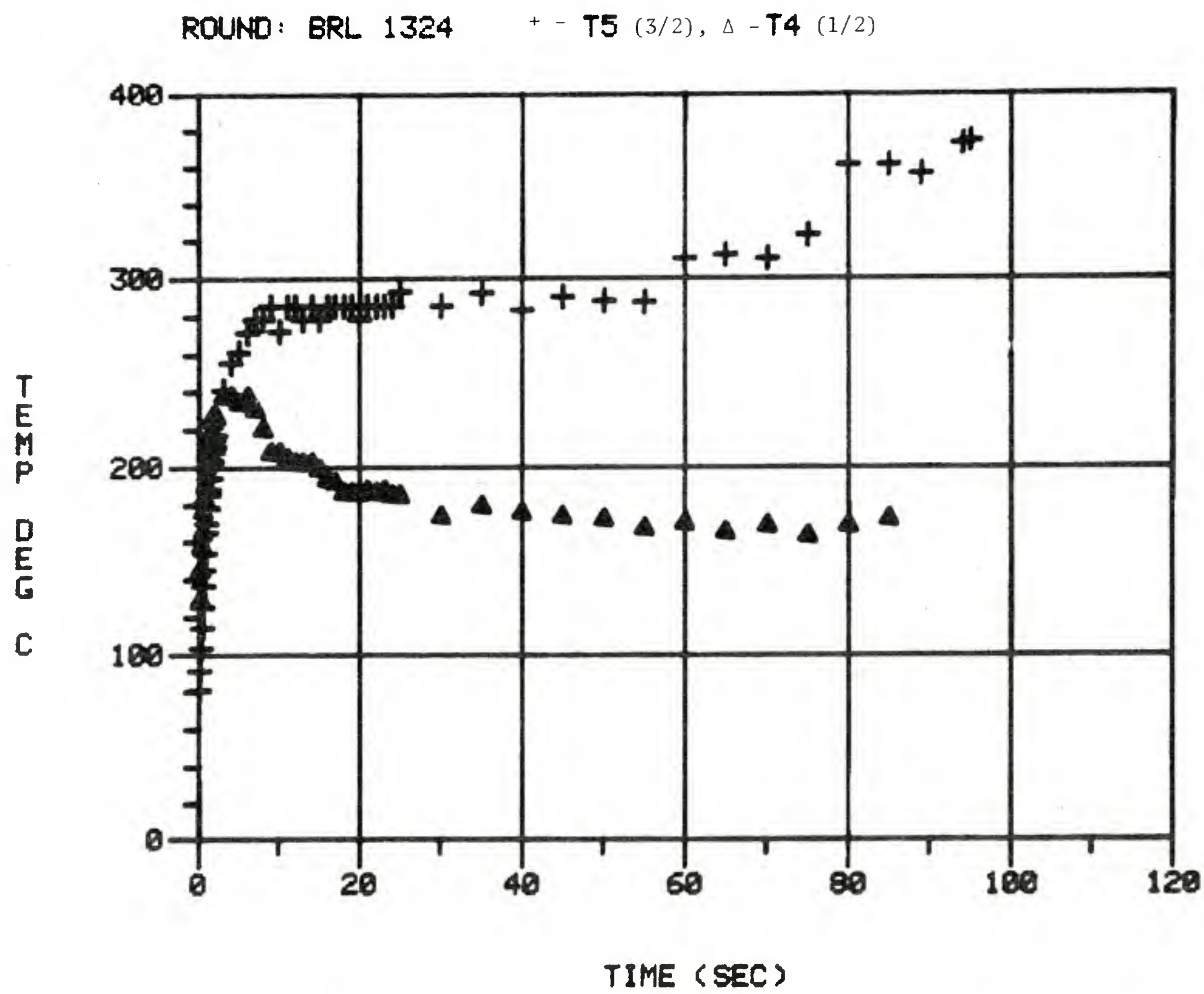


Figure 25. BRL 1324: Time versus Temperature for Positions 4 and 5 (0-120 s).

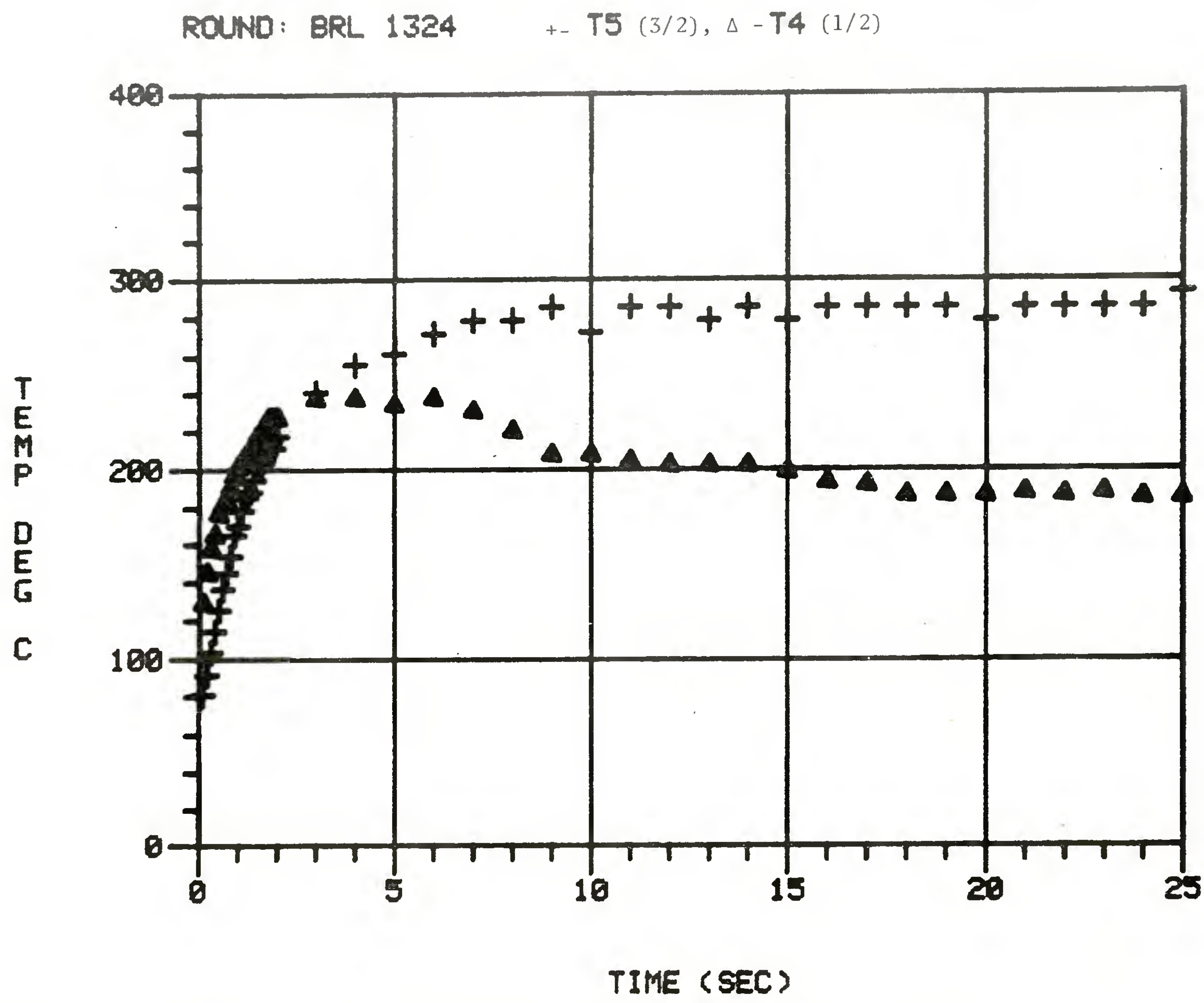


Figure 26. BRL 1324: Time versus Temperature for Position 4 and 5 (0-25 s).

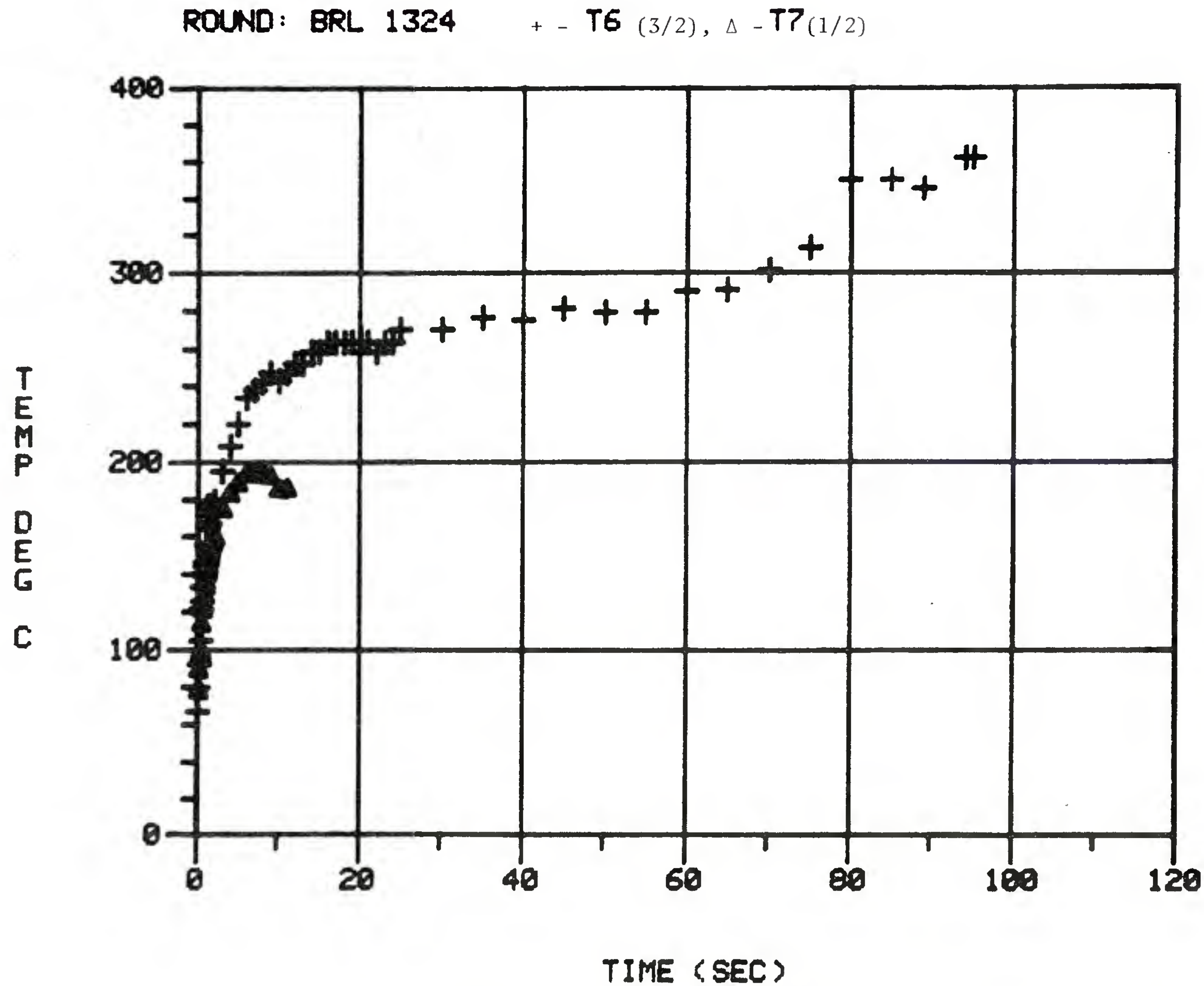


Figure 27. BRL 1324: Time versus Temperature for Positions 6 and 7 (0 - 120 s).

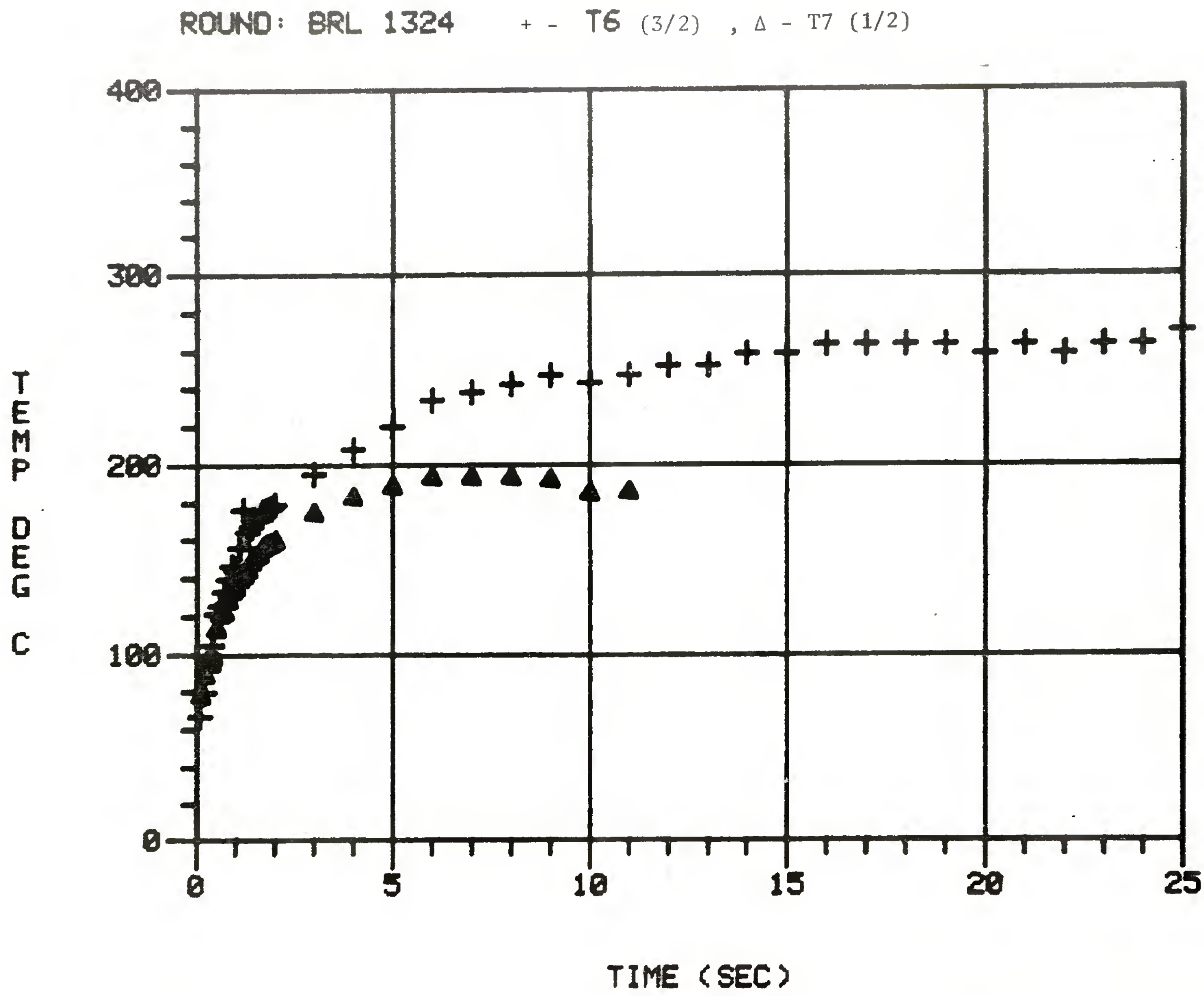


Figure 28. BRL 1324: Time versus Temperature for Positions 6 and 7 (0 - 25 s).

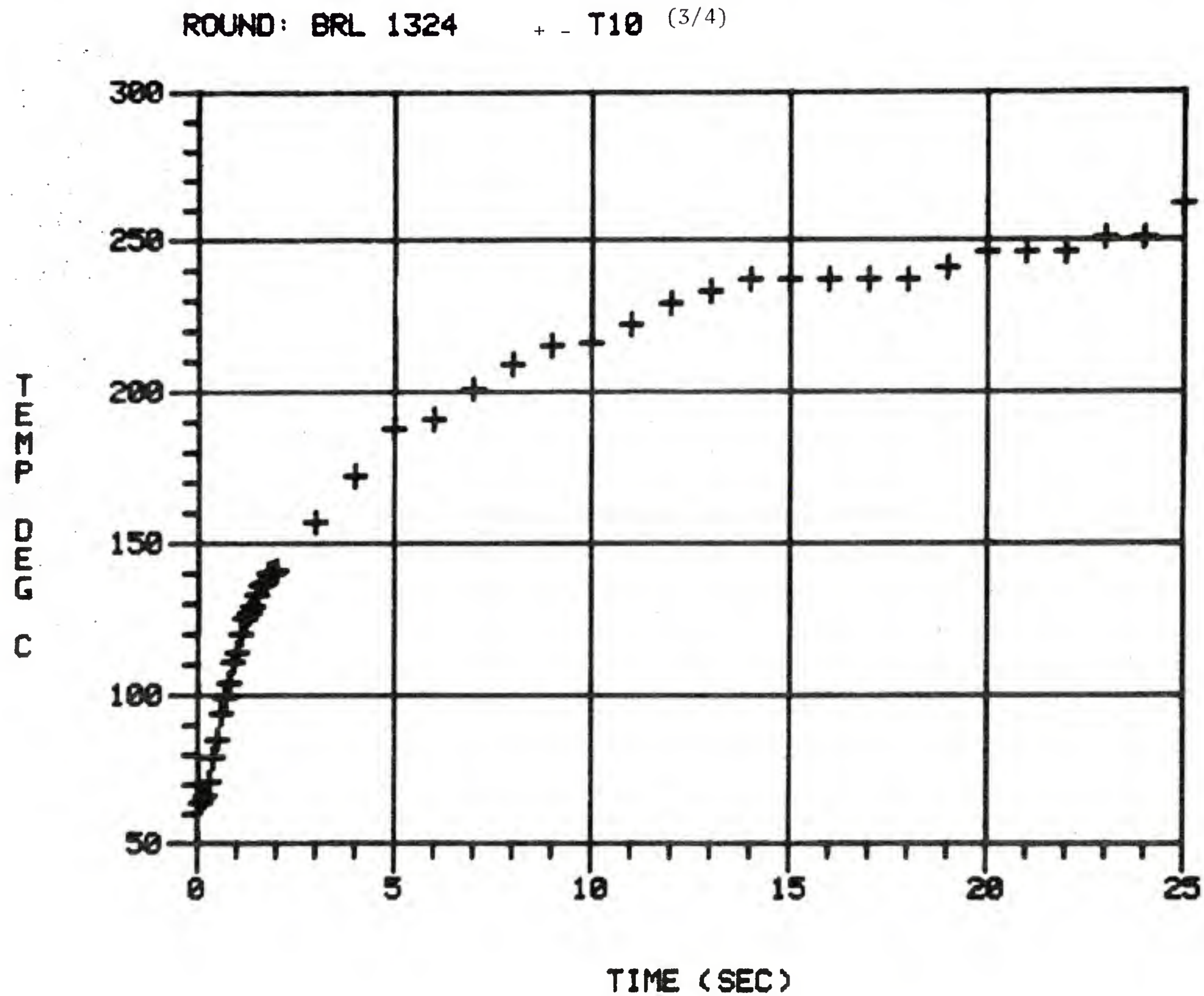


Figure 29. BRL 1324: Time versus Temperature for Position 10 (0-25 s).

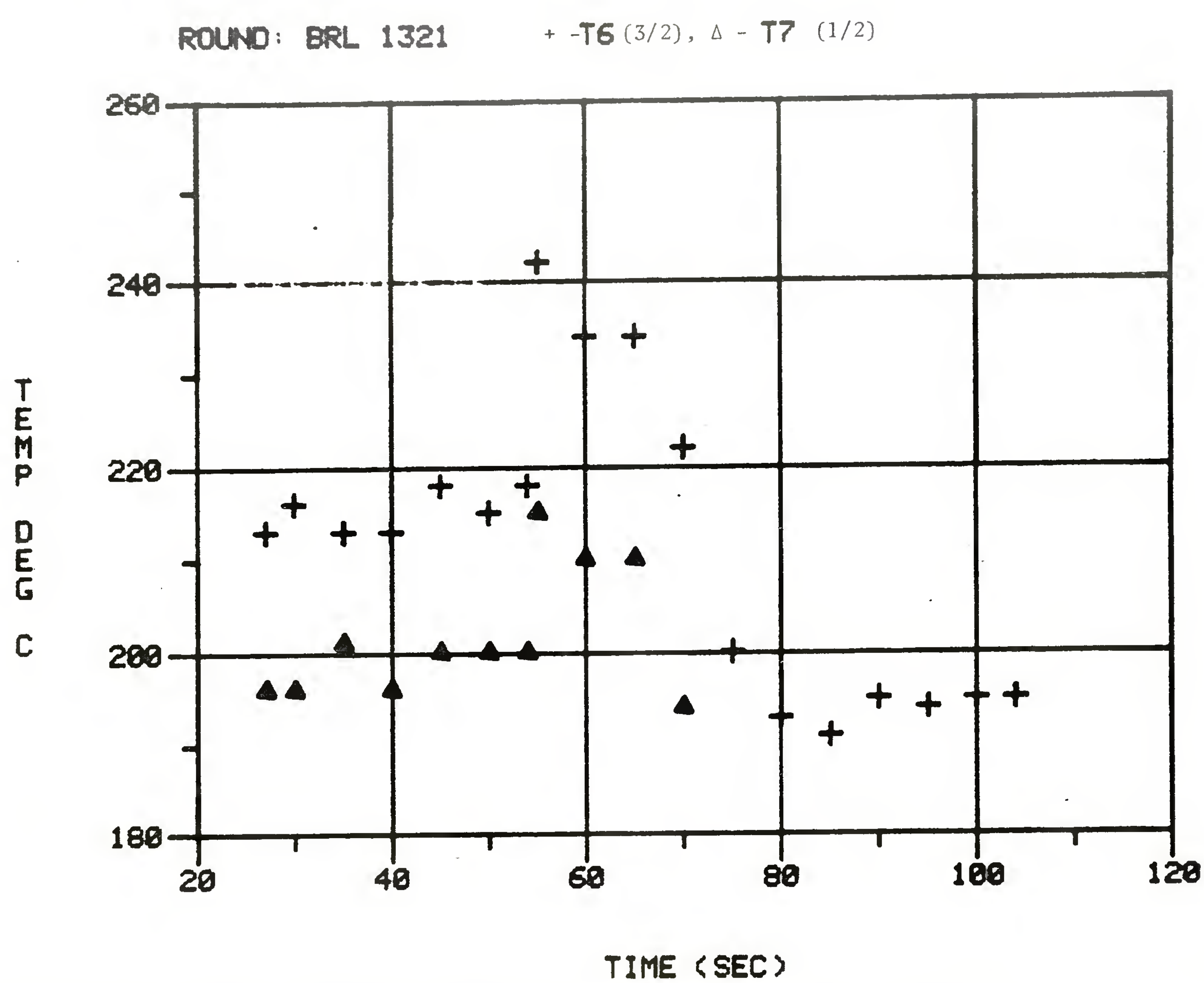


Figure 30. BRL 1321: Time versus Temperature for Positions 6 and 7 (20-120 s).

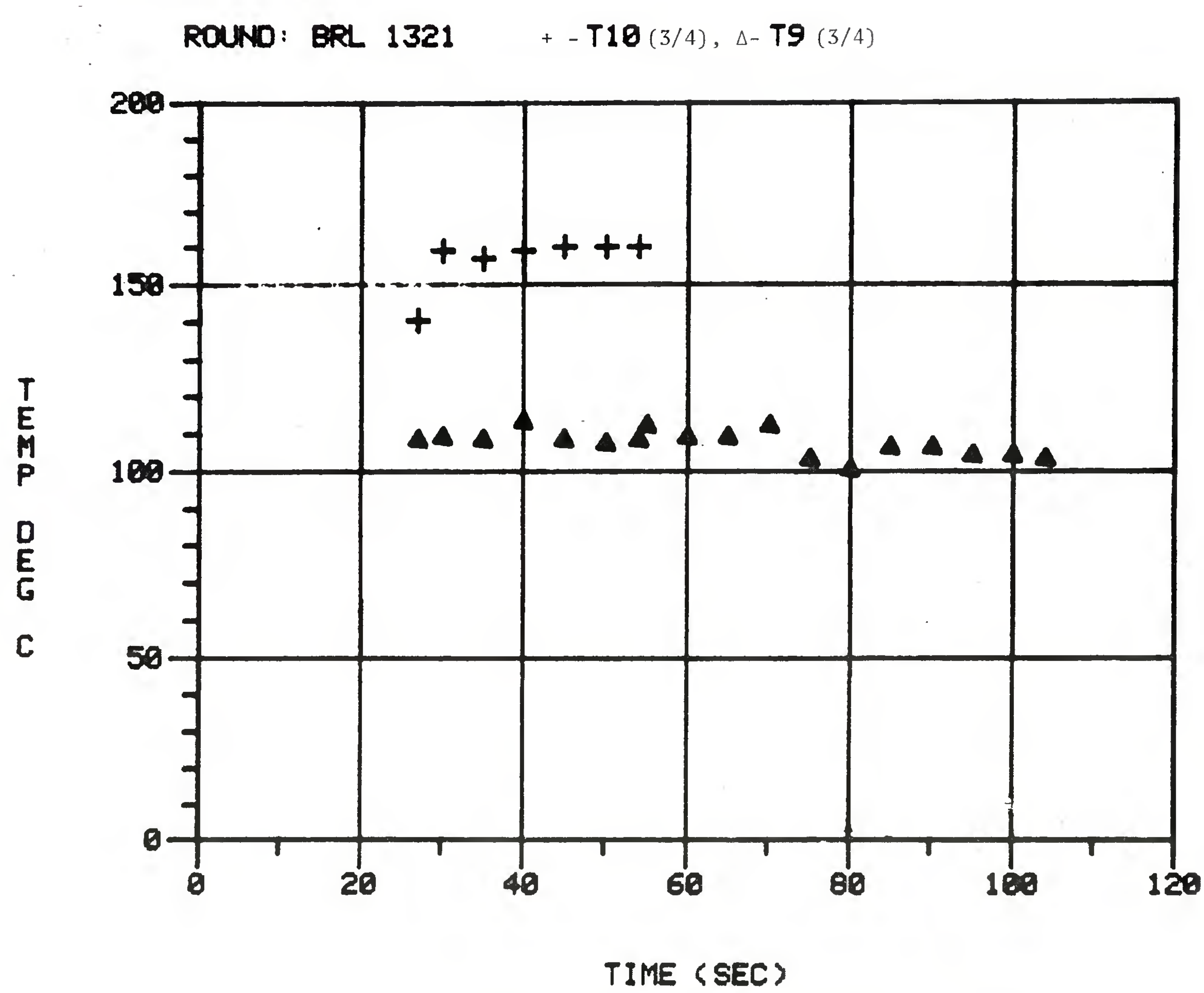


Figure 31. BRL 1321: Time versus Temperature for Positions 9 and 10 (0-120 s).

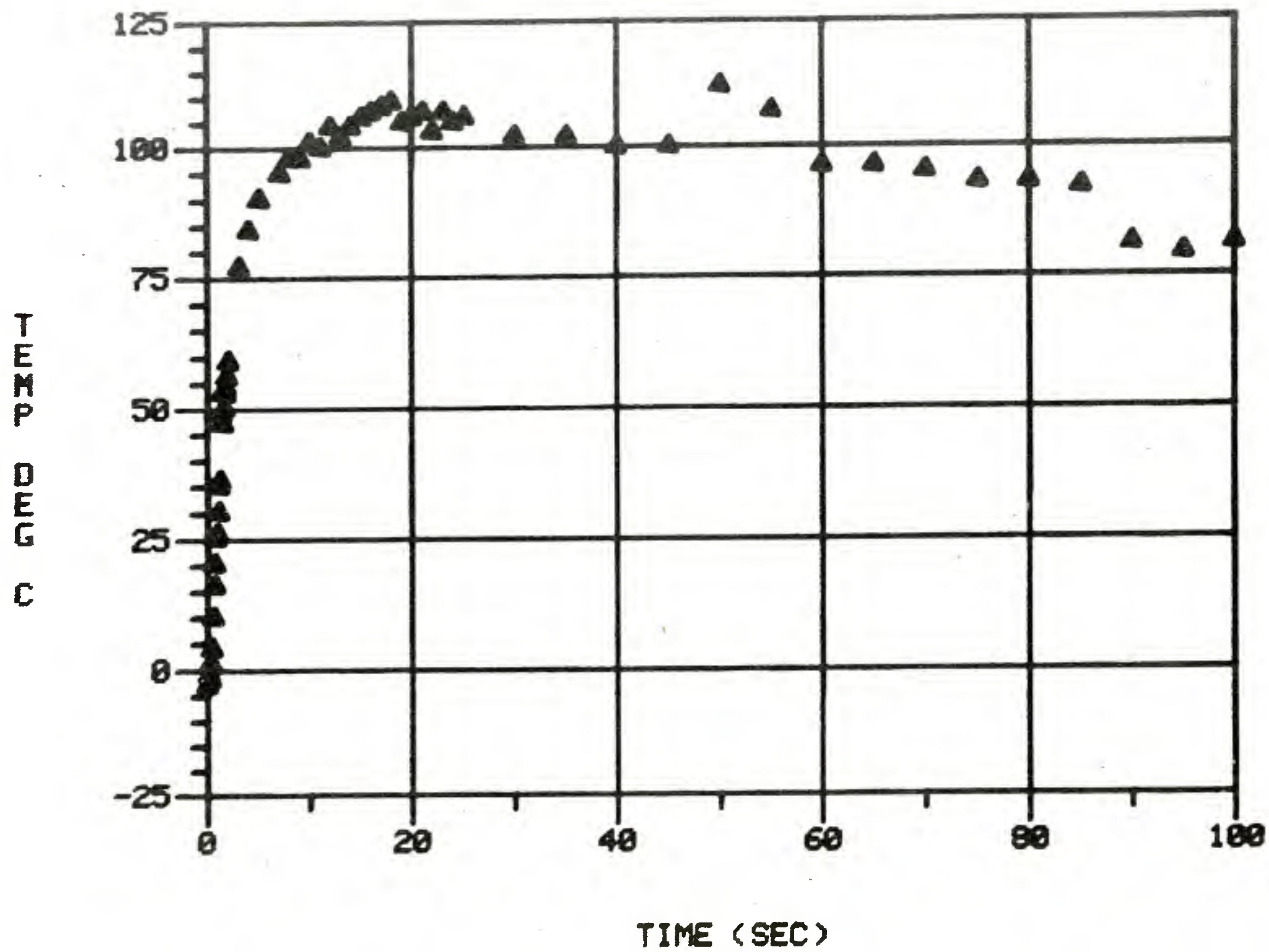


Figure 32. Round: BRL 1322. Temperature Difference Between T3 and T2.

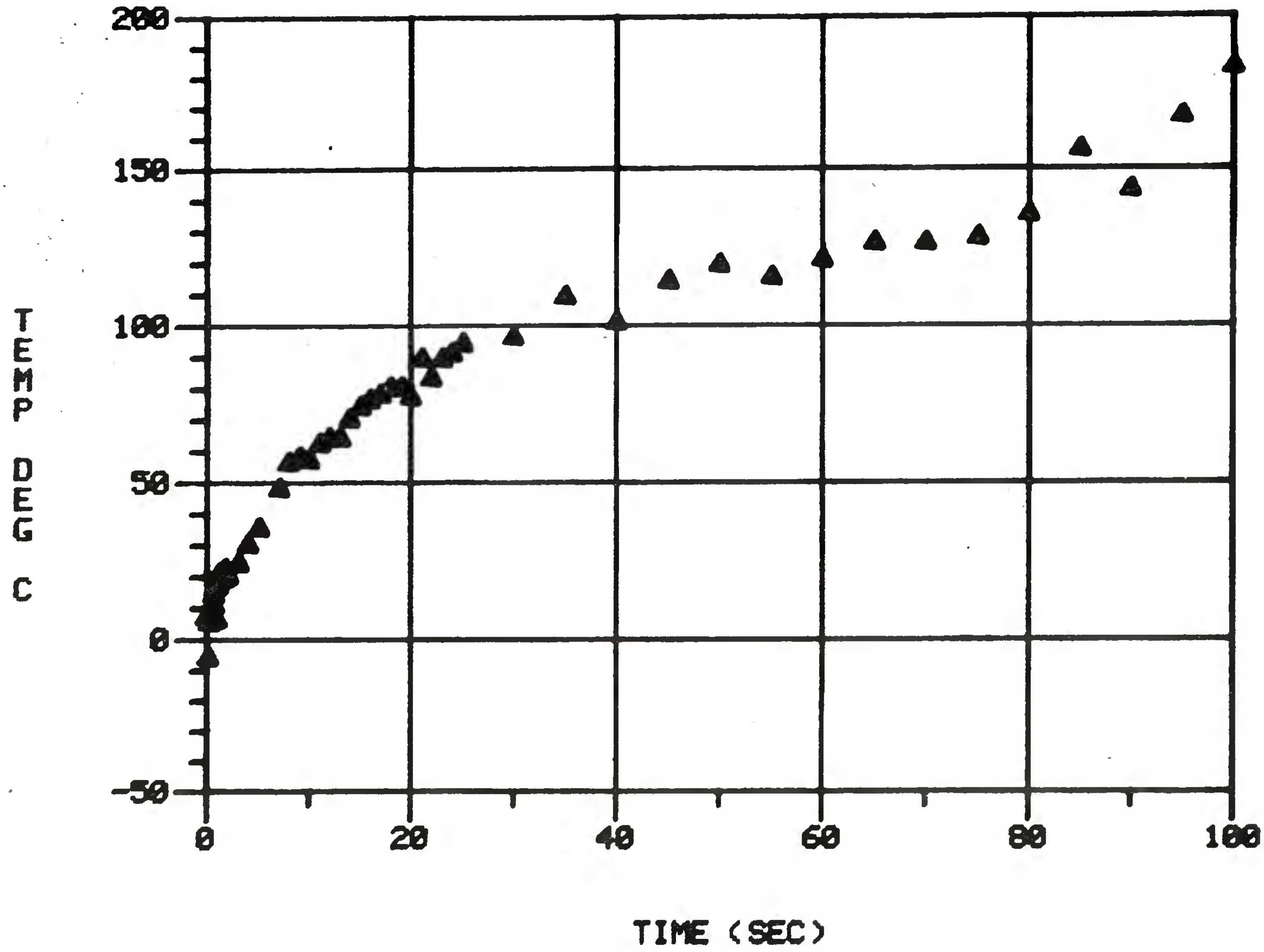


Figure 33. Round: BRL 1322. Temperature Difference Between T5 and T4.

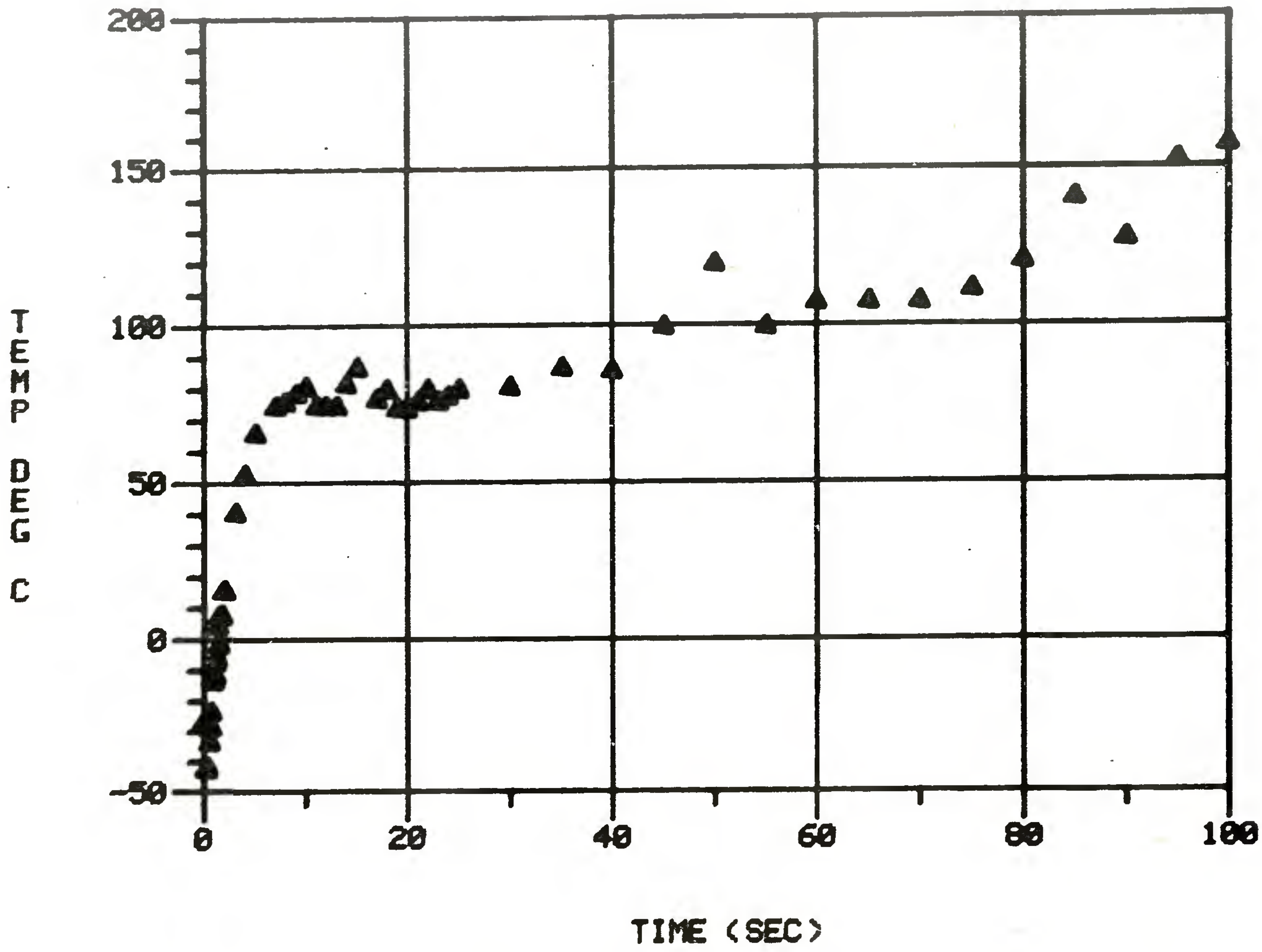


Figure 34. Round: BRL 1322. Temperature Difference Between T6 and T7.

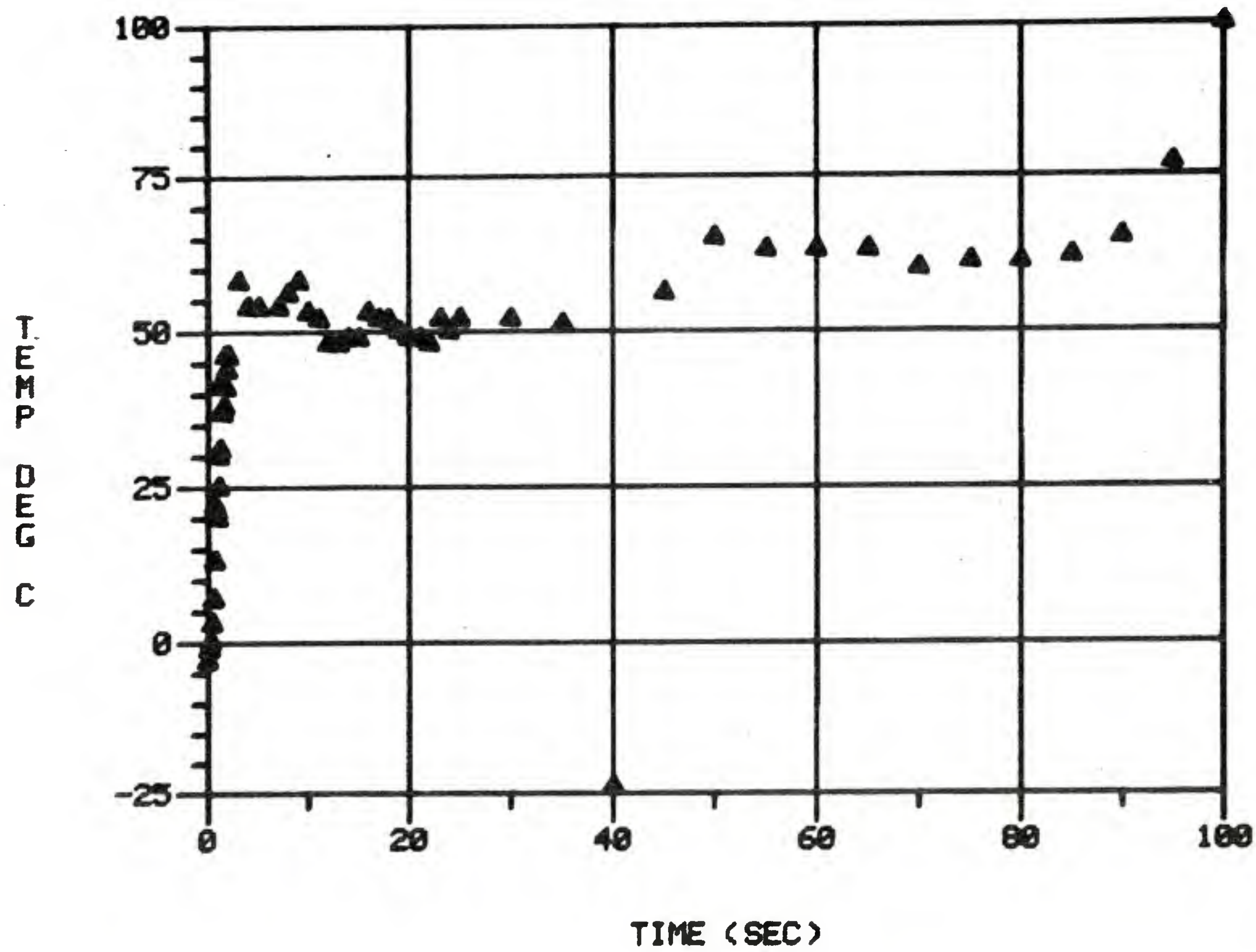


Figure 35. Round: BRL 1322. Temperature Difference Between T9 and T8.

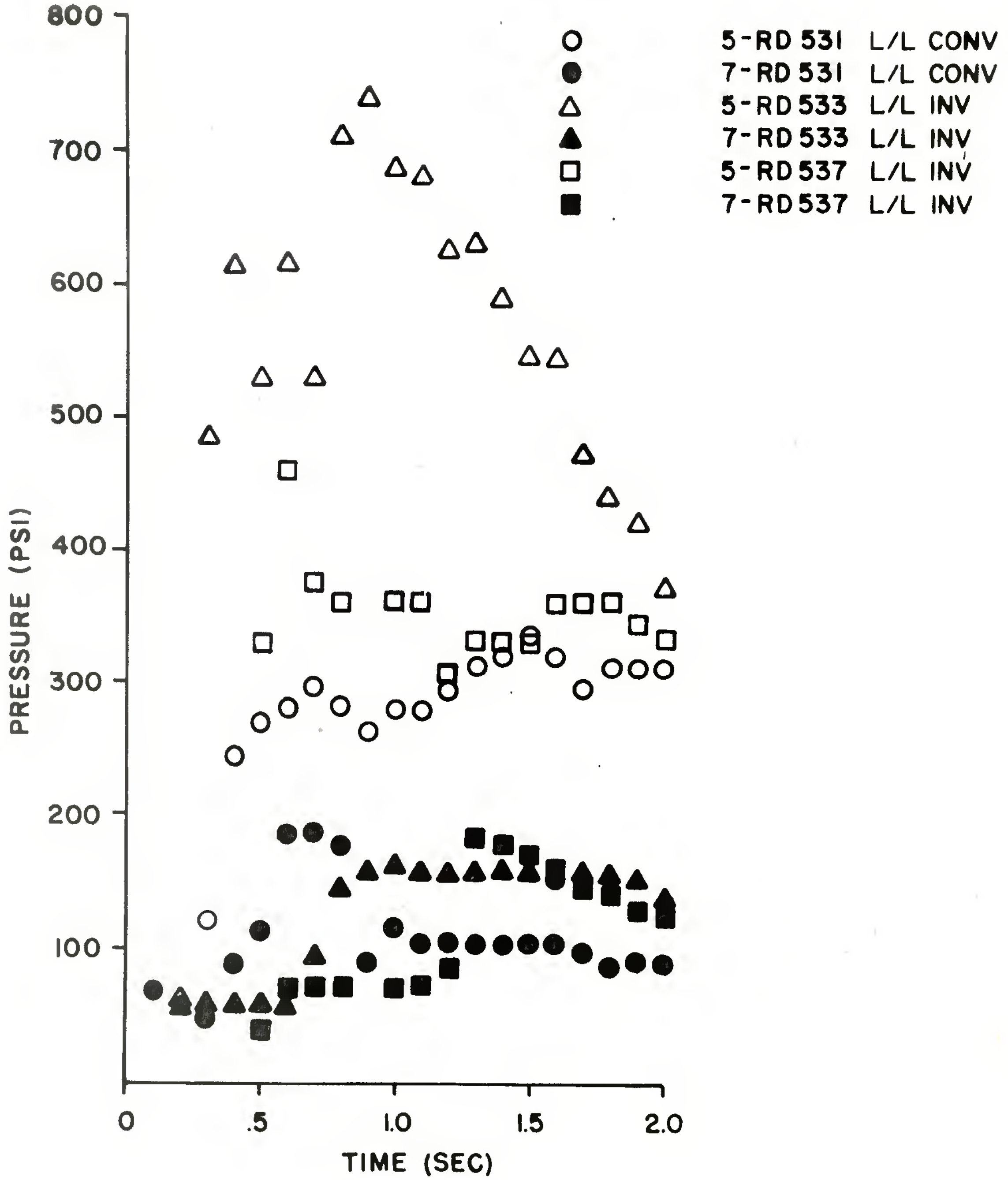


Figure 36. Pressure measurements from 1975 tests (Ref. 1).

REFERENCES

1. W.P. D'Amico, W.H. Clay, A. Mark, and W.H. Mermagen, "In-Flight Payload Temperature Measurements for the XM736 Binary Projectile", BRL MR 2560, November 1975, AD B008702L.

APPENDIX A

ERROR ANALYSIS FOR TEMPERATURE MEASUREMENT

The thermistor/voltage divider network employed for the XM736 was initially designed and calibrated for temperature measurement between 20 and 200°C. The data reported herein indicated substantially higher levels, and this appendix will comment on the accuracy of those temperatures. Four areas will be considered: calibration, response time, analog measurement, and analog to digital conversion.

A. Calibration

A thermistor with mount similar to the type used in the tests was calibrated from 22 to 300°C. The calibration data were then fit using measurements up to 200°C and then using all measurements. Both of these calibrations were used to calculate the resistance of the thermistor at 300°C. The calibration using data only up to 200°C was in error by 5°C. Hence, temperature data in the vicinity of 350°C, which was calculated using calibration data up to 200°C, is in error by at least 5°C and perhaps as much as 10°C.

B. Response Time

The response times of mounted thermistors were measured. Several experiments were performed using mounts with protrusion depths up to 1½ inches and with an 80 gm aluminum plate as a heat sink. Data were gathered in a quiescent oil bath and in a boiling water bath. Table A1 lists the various tests and the measurements of response times. Interpretation of these results and application to the projectile case are not straightforward due to the variable state of rotation of the liquid simulants during flight. The response time of a particular transducer is a function of the heat input. The heat input is a function of the fluid flow, i.e., the convective heat transfer coefficient, and the properties of the fluid and the mount. For example, the response times in the oil bath were considerably longer than those in boiling water. The response times of the various mounts in the projectile are probably very rapid during the liquid spin-up process that occurs within the first few seconds of flight, but subsequently become longer when the liquid is in a state of quasi-rigid body rotation. The response time is also dependent upon the temperature of the fluid as seen from the first two tests listed in Table A1. There does not appear to be a significant difference in the response time of two different thermistors in the same type mount. Any differences may be due to the depth of the thermistor from the liquid/epoxy interface. The large steel payload canisters act as heat sinks, and this effect is also unknown. The last two tests listed in Table A1 indicated that a plate with a small mass substantially modified the response time of the thermistor/mount. Figures A1 and A2 provide the actual voltage versus time traces of some of the tests listed in Table A1. The voltage is related to the

resistance of the thermistor which is in turn calibrated to temperature.

C. Analog Measurement

The measurement system is designed in advance to optimally measure temperatures within a certain range. The variables that may be selected are the resistance of the thermistor (R_T), the resistance of the series resistor (R_S), and the voltage applied to the divider network. For telemetry applications, the voltages supplied to a VCO are normally % ±2.5 volts or, as in our case, 0 to 5 volts. Hence, a controlled voltage, E, is normally selected to be slightly under the maximum allowable voltage, say 4.7 volts. The voltage drop across the series resistor is V and is monitored. Then, the ratio V/E can be related to the resistance of the thermistor which is calibrated to temperature. This voltage divider has a minimum measurement error when R_S is approximately equal to R_T. The present measurement system employed 1KΩ series resistors and thermistors with resistances of approximately 1KΩ at 120° C. The voltage-resistance and the voltage-temperature variation relationships are:

$$V = ER_S \,/\, (R_T + R_S). \qquad \text{(A1)}$$

For a thermistor where T_o, R_o, and β are constants,

$$R_T = R_o \exp\left[\beta\,(1/T - 1/T_o)\right] \quad , \qquad \text{(A2)}$$

then

$$\Delta T \simeq \frac{\Delta V}{E} \left[(T^2/\beta)\ (R_S + R_T)^2/R_S R_T\right] \quad . \qquad \text{(A3)}$$

Hence, for $T=300^{\circ}C$ ($573^{\circ}K$), $R_S=1K\Omega$, $R_T=50\Omega$, and $\beta=3500^{\circ}K$,

$$\Delta T \simeq 2000 \frac{\Delta V}{E} \qquad \text{(A4)}$$

Therefore, a small uncertainty in voltage produces a large uncertainty in temperature. This type of variation is not critical in the analog sense, since voltages can be measured very accurately. The error in the temperature measurement hinges on the analog to digital conversion of $\Delta V/E$.

D. Analog to Digital Conversion

The data provided within this report were reproduced from an analog form onto strip chart records. The accuracy of such a procedure is only 1/100. Based upon A4, an uncertainty of $20^{\circ}C$ exists for temperatures in the $300^{\circ}C$ range. This error could be overcome by using an analog to digital converter where accuracies are easily 1/1000. Under such circumstances the selection of R_T and R_S would not be critical, and the

calibration error would then be the largest error in the amplitude resolution of the temperature.

E. Summary

The errors of temperature measurement involve phase and amplitude. The resolution of the temperature amplitude is approximately ±20°C for the very high temperatures reported and is probably ±5°C for substantially lower temperatures. The phase delay is unknown, but it should be small for early flight times and larger for longer flight times. In general, the reported temperatures are probably low in amplitude and slightly delayed in time.

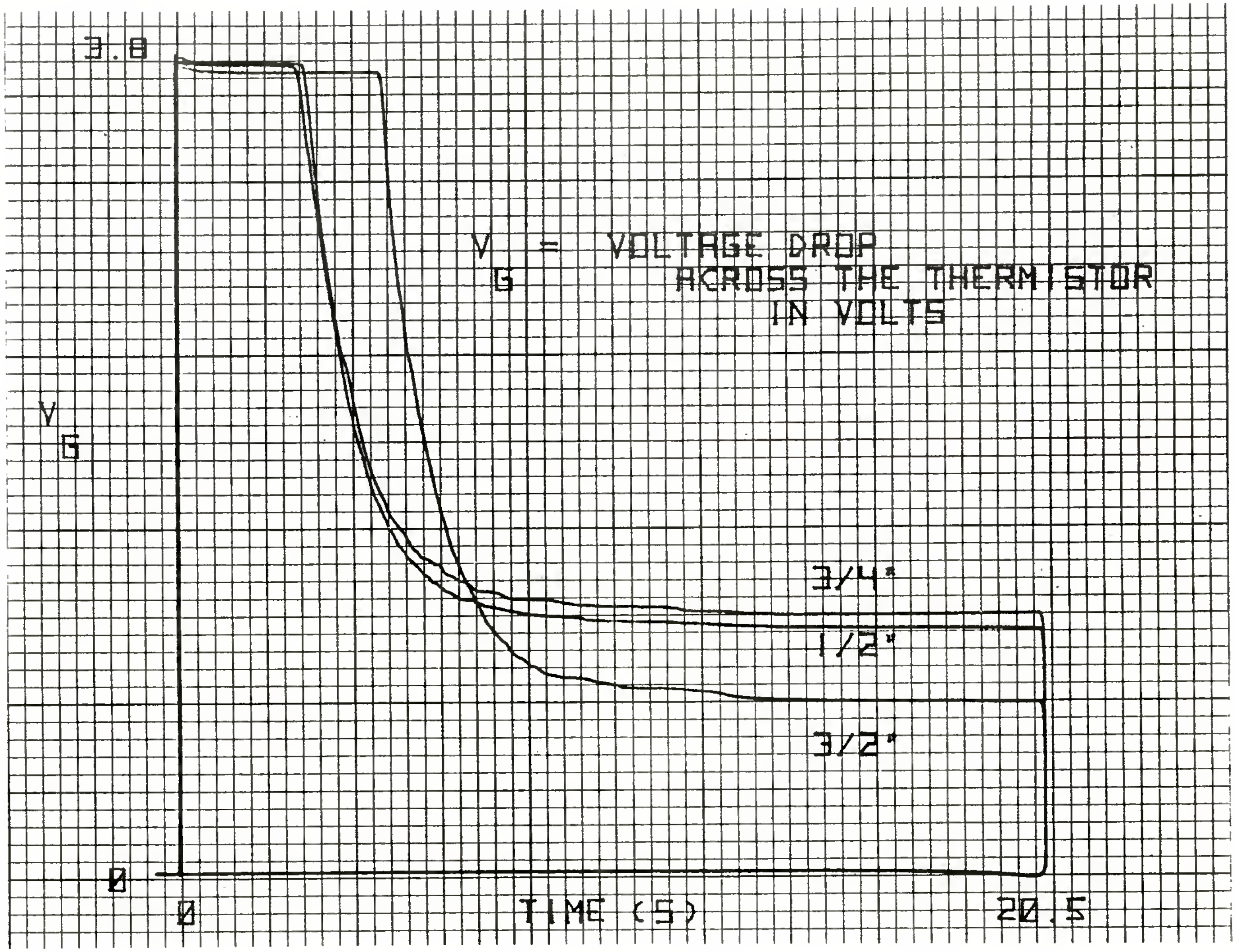


Figure A1. Thermistor/Mount Response Times.

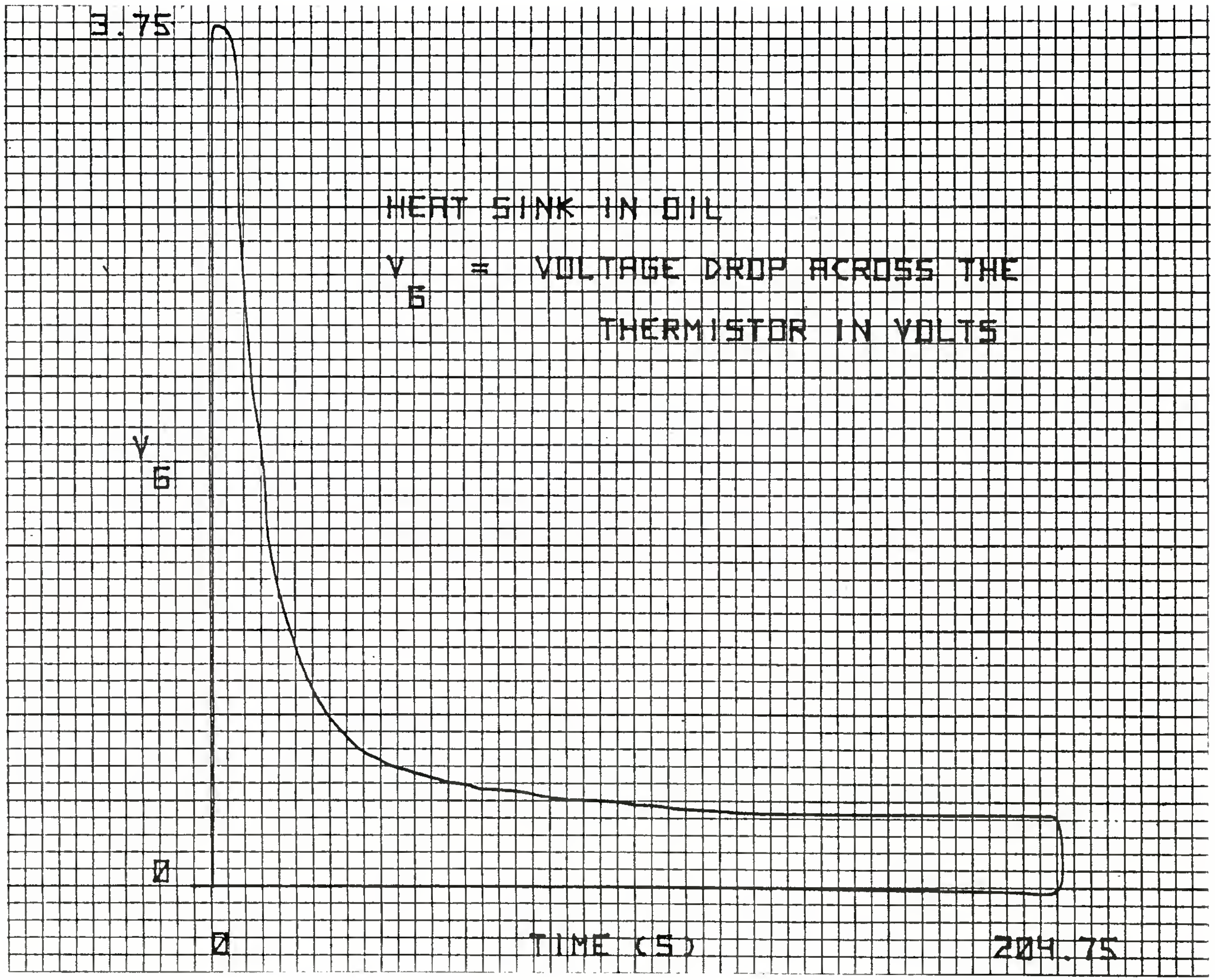


Figure A2. Response Time with a Thermal Sink.

TABLE A1.

Response Time Tests

Type Bath	Type Thermistor	Cold Bath (°C)	Hot Bath (°C)	Response Time[5] (s) 60%	90%
Oil	A-Flush[1]	25	154	11.5	21.3
Oil	A-Flush	25	236	7.3	13.4
Oil	B-Flush[1]	25	253	6.6	13.1
Oil	Glass-50KΩ[2]	25	263	3.0	3.7
Water	Glass-50KΩ	25	99.7	---	1.7
Water	A-Flush	22	99.7	---	2.5
Water	1½[3]	15	99.8	1.2	2.7
Water	3/4[3]	15	99.6	1.2	2.7
Water	1/2[3]	16	99.2	1.3	3.0
Water	Heat Sink[4]	24	99.8	6.5	16.9
Oil	Heat Sink[4]	25	288	11.4	32

[1] A and B are flush mounted thermistors.
[2] A non-miniature bare thermistor (not the type mounted for projectile temperature measurement).
[3] Thermistors in 1½, 3/4, and 1/2 inch brass mounts.
[4] A thermistor in a 1/4 inch mount screwed into an 80 gm aluminum plate.
[5] Time to 60% or 90% of the steady state temperature.

APPENDIX B

ROUND BRL 978 FIRING DATA 27 SEPT 76 CHARGE 7 QE: 42 DEG

TIME(S)	TEMPERATURE(DEG C)				GAGES 1 TO 10					
	(1/2)	(1/2)	(FLH)	(3/2)	(1/2)	(3/4)	(1/4)	(1/2)	(FLH)	(3/4)
0.2	32	38	55	45	42	44	61	51	44	17
0.4	39	45	55	73	59	77	88	81	59	46
0.6	52	58	63	95	77	104	100	105	63	74
0.8	60	70	66	112	92	122	109	118	63	96
1.0	70	82	66	125	102	134	113	128	61	112
1.2	74	89	59	134	109	144	115	133	56	126
1.4	80	96	58	141	115	153	116	138	52	136
1.6	85	100	56	147	120	160	117	143	52	143
1.8	89	106	53	151	125	165	118	148	49	149
2.0	90	109	53	155	128	167	118	148	49	154
3.0	101	121	49	170	137	180	119	154	49	155
4.0	103	126	49	175	140	183	118	155	45	178
5.0	109	130	51	186	145	188	119	155	49	188
6.0	111	130	46	187	146	191	116	152	47	190
7.0	112	133	44	190	148	195	117	152	45	193
8.0	115	134	44	190	147	197	116	153	45	197
9.0	116	135	44	197	147	195	112	153	47	203
10.0	116	135	42	197	147	193	112	153	45	205
11.0	118	137	44	203	150	193	112	153	47	207
12.0	120	138	44	208	150	191	111	153	47	211
13.0	120	138	44	210	149	190	109	152	47	207
14.0	122	140	46	215	149	188	109	152	49	207
15.0	123	140	46	215	149	188	109	152	49	207
16.0	123	140	46	217	149	188	108	152	49	209
17.0	125	140	44	217	148	188	108	150	49	211
18.0	125	140	46	217	147	188	108	160	50	211
19.0	126	140	46	219	145	188	107	148	50	211
20.0	126	140	44	224	145	188	107	148	50	211
25.0	128	139	46	233	147	190	108	152	55	218
30.0	129	140	46	236	144	188	107	151	57	220
35.0	129	140	50	238	143	186	107	149	58	222
40.0	130	140	48	241	142	186	106	149	60	224
45.0	131	140	52	244	139	186	104	148	64	221
50.0	130	139	52	247	136	184	104	147	65	221
55.0	128	137	52	244	135	181	107	144	67	224
60.0	129	137	54	247	135	182	107	142	67	227
62.0	129	137	55	244	133	181	109	140	67	227

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